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An annotated type catalogue of the frogs (Amphibia: Anura: Limnodynastidae, Myobatrachidae, Pelodryadidae) in the collection of the Western Australian Museum

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ABSTRACT – An annotated catalogue is provided for all primary and secondary type specimens of frogs (Amphibia: Anura) currently and previously held in the herpetological collection of the Western Australian Museum (WAM). The collection includes a total of 613 type specimens (excluding specimens maintained as possible paratypes) representing 55 species or subspecies of which four are currently considered junior synonyms of other species. The collection includes 44 holotypes, 3 lectotypes, 36 syntypes, 462 paratypes and 68 paralectotypes. In addition, the collection includes 392 specimens considered possible paratypes where paratype specimens could not be confirmed against specimens held in the WAM for five species (*Heleioporus barycragus, H. inornatus, H. psammophilus, Crinia pseudinsignifera* and *C. subinsignifera*). There are 23 type specimens and seven possible paratypes that have not been located, some of which were part of historic disposal of specimens, and others with no records of disposal, loan or gifting and are therefore considered lost. Type specimens supposedly deposited in the WAM by Harrison of the Macleay Museum, University of Sydney, for *Crinia rosea* and *Pseudophryne nichollsi* were not located during the audit of types and are considered lost.

KEYWORDS: type specimens, holotype, lectotype, syntype, paratype, paralectotype, allotype, frog

INTRODUCTION

Since the establishment of the Western Australian Museum (WAM) in 1891, its natural history collection has grown substantially to become one of the largest collections in Australia, and one of the largest regional collections in the world. Amphibian specimens make up about 29,000 of the 160,000 specimens in the herpetological collection. Initially herpetofauna specimens were accessioned into a series of six general hardcopy catalogues from 1891 to 1912. The registers were used to document all material obtained by the museum, including material for terrestrial and aquatic zoology, history, anthropology and archaeology collections. The earliest anuran acquisition by the WAM listed in the WAM donations register 1896–1900, dated 20 July 1896 was part of a group of specimens. The entry states '2 bottles containing…2 frogs, 1 snake, 15 lizards, 26 (insects and crabs)' from 'Broome'; however, no further information is provided. The acquisition was also published in the local press on 10 August 1986 (Anonymous 1986), where many early donations and purchases of the WAM were published prior to the use of formal registers. The article lists the acquisition as a museum purchase, stating 'three bottles containing two frogs, one snake, 15 lizards, 26 insects and crabs, etc' (Anonymous 1896). The species identification of the two frog specimens or their whereabouts is unknown as no registration number, additional specimen information or species identification are provided in the register or local press article.

In 1912 a hardcopy catalogue was established specifically for herpetological specimens. Specimens accessioned into the herpetological catalogue obtained a registration number prefixed with 'R' for 'reptiles', although this collection also includes amphibians. This prefix is still in use to denote registration numbers and specimens in the herpetological collection. Where associated specimens and information could be identified for pre-departmental registration numbers, the specimens were re-catalogued into the new cataloguing

system and given 'R' numbers. It is not known if this was completed for the entire collection; however, after review of historic catalogues, an attempt to re-catalogue specimens accessed prior to the current herpetology catalogue (pre-1912) was completed in stages by numerous museum staff. Many historic specimens have notations indicating a specimen has been re-catalogued in the new system and the date when this was done, sometimes signed by the person responsible. A large number of catalogue entries are not accompanied with notations of re-cataloguing and there is no information about specimens gifted to other institutions, discarded or lost. The earliest anuran specimen documented in the WAM herpetofauna catalogue is a *Myobatrachus gouldii* (turtle frog), R39, accessioned 30 August 1912. All specimens formerly registered in the hardcopy catalogues given registrations bearing the 'R' prefix have since been entered into the current electronic database of herpetological specimens. Any new specimens registered into the herpetological collection are now entered into the electronic herpetological database.

The collection is primarily composed of Western Australian species, but does contain comparative material from other Australian states and some international locations, including Malaysia (36 species), Indonesia (10), and New Guinea (10), and species from other countries including Canada, India, Nicaragua, Philippines, Solomon Islands, U.K., U.S.A. and various countries in Africa. Anurans are represented by a total of 29,014 registered specimens (as of 28 December 2016), with approximately 2,100 lots of unregistered tadpoles and eggs. Adults and juveniles have been fixed in a 10% formalin solution and are stored in a 70% ethanol solution and tadpoles in 5% formalin solution. There are also select alizarin-alcian stained and skeletal preparations of adults for some species. Over 7500 type specimens are held in the reptile and amphibian collection with 613 specimens representing types of 55 anuran species or subspecies: 83 primary types (44 holotypes, 3 lectotypes and 36 syntypes) and 530 secondary types (462 paratypes and 68 paralectotypes). A further 392 specimens are regarded as possible paratypes for species or subspecies where original descriptions clearly used other specimens, in addition to the type, which often attributed to description of variation or are listed as a specimen examined; however, insufficient detail is provided to confirm the identity of these paratypes. Potential paratypes listed here are specimens that were probably included in the description of the species based on the often limited information provided by authors; however, they cannot be confirmed. We recognise possible paratypes for five species: *Heleioporus barycragus, H. inornatus, H. psammophilus, Crinia pseudinsignifera* and *C. subinsignifera*. In some cases, the number of possible paratypes exceeds the number of specimens listed in the original description while in others there are fewer which suggests the number of confirmed type specimens and the number of specimens considered lost may be greater or less than previously indicated. Historic disposal of specimens at the WAM has occasionally occurred with the reason for most not well documented; however, in the past, disposals have often been attributed to poor condition of specimens. In some circumstances, the taxonomic status of a species was believed to be resolved and additional specimens or those in poor condition were considered not necessary to retain in the collection. The disposal of specimens following registration into the WAM herpetological collection has previously been noted (Smith 1981). The WAM type collection currently holds type material for 49 of the 85 currently recognised native anuran species known to occur in WA. Of the 64 anuran species or subspecies described from Western Australian localities, type material for 45 (70%) are currently housed in the WAM collection. The remaining 19 species described from WA localities not represented in the WAM anuran type collection include two Pelodryadidae (*Litoria adelaidensis* and *Litoria cyclorhyncha*), six Limnodynastidae (*Heleioporus albopunctatus*, *Heleioporus eyrei*, *Limnodynastes dorsalis*, *Neobatrachus wilsmorei*, *Neobatracthus pelobatoides*, *Notaden nichollsi*) and 11 Myobatrachidae (*Myobatrachus gouldii*, *Crinia georgiana*, *Crinia glauerti*, *Crinia insignifera*, *Geocrinia leai*, *Geocrinia rosea*, *Pseudophryne guentheri*, *Pseudophryne nichollsi*, *Pseudophryne occidentalis*, *Uperoleia marmorata* and *Uperoleia mjobergii*).

Until the early 2000s, the taxonomic interests of WAM herpetology curators was almost exclusively focussed on Western Australian reptiles. In contrast, most of the early taxonomic work on Western Australian frogs was carried out by researchers based in the U.K. or U.S.A. until about the mid-20th century. Many of the described species during this early period have widespread distributions, with types taken from eastern or northern states and territories, but with ranges extending into Western Australia. The result is that there are few types of such widespread species in the WAM from these early descriptions. Beginning in the 1950s and continuing to the present day, frog biologists based at the University of Western Australia (UWA) such as Albert 'Bert' Russell Main, Murray John Littlejohn and John 'Dale' Roberts focussed on aspects of evolution and ecology of frogs (see Shea 2014), with taxonomic outputs as a result of their findings, especially with species endemic to arid and south-western WA. In contrast, researchers from South Australia, usually led by Michael 'Mike' John Tyler and Margaret Davies from the University of Adelaide and the South Australian Museum, along with

Angus Anderson Martin and Graeme Field Watson (University of Melbourne), carried out extensive early fieldwork in the Kimberley region in the 1970s and 1980s with a focus on taxonomy. Collecting permits issued for fieldwork in Western Australia require holotypes and a portion of the paratypes collected to be deposited at the WAM, resulting in many of the South Australian group's Kimberley types being deposited here. Collection of specimens from the Kimberley was also supported by the collecting efforts of Lawrence 'Laurie' Alex Smith and Ronald 'Ron' Eric Johnstone as part of WAM's Kimberley expeditions in the 1970s and 1980s. More recently, Doughty and colleagues have added Kimberley and arid zone type specimens as part of an active research programme on frog systematics (e.g. Doughty and Anstis 2007; Doughty and Roberts 2008; Doughty et al. 2009; Anstis et al. 2010; Catullo et al. 2011; Doughty 2011; Catullo et al. 2014; Anstis et al. 2016).

The WAM published a list of types annually in the WAM Annual Report from 1960 to 1969, discontinued in 1970 (Anonymous 1970). A total of 10 parts of the type list were presented, of which only parts 2 (1960–61), 4 (1962–63), 5 (1963–64), 6 (1964–65), 8 (1966–67) and 10 (1968–69) included anuran material (Anonymous 1961, 1963, 1964, 1965, 1967, 1969). The Annual Report type lists present primary types for 12 anuran type specimens in the herpetological lists, compiled by Glen Milton Storr. Primarily holotypes and lectotypes, and occasionally syntypes and neotypes, were listed, with no secondary types listed. Since the 1970 Annual Report, no further type lists or catalogues have been published for the type material held in the herpetological collection of the WAM. In accordance with Recommendation 72F of the International Code of Zoological Nomenclature (ICZN 1999), a type specimen audit was commenced in order to publish a current type catalogue of the material held in the WAM herpetological collection. Due to the size of the herpetological type collection, a decision to publish separate type catalogues by taxonomic group was made. The first of a series of publications presenting the type material held in the herpetological collection of the WAM, a type catalogue of the turtles (Chelidae) was published in mid-2015 (Ellis and Georges 2015). The present type catalogue is the second of this series.

METHODS

Information on type specimens was obtained from the original description and compared with information retrieved from accession data on the museum database, jar labels, personal communications and subsequent publications relating to relevant type material. All type specimens in the collection of the WAM were examined in addition to label information and notations. Extensive searches of the collection, accession data, original descriptions and other records were undertaken during the audit to locate missing specimens or those lacking data. This catalogue also includes type specimens of species that have, since their description, been synonymised and/or resurrected from synonymy with other taxa. This catalogue was prepared in accordance with the rules, recommendations, definitions and amendments of the International Code for Zoological Nomenclature (ICZN 1999, 2003, 2012).

As higher level frog taxonomy is in a state of flux owing to new molecular genetic phylogenies, we follow the Australian Society of Herpetologists (ASH) Species List of Australian Amphibians and Reptiles as of 20 December 2016 (http://www.australiansocietyofherpetologists.org/position-statements/, position statement #3). This list maintains usage of the genus *Cyclorana* Steindachner (contra Frost et al. 2006; Duellman et al. 2016; Dubois and Frétey 2016) and also does not recognise *Ranoidea* Tschudi (Dubois and Frétey 2016; formerly the *Dryosophus* Fitzinger resurrected by Duellman et al. 2016) for approximately half the species of *Litoria*.

FORMAT

This catalogue follows the format of a previous WAM type catalogue by Ellis and Georges (2015).

ORIGINAL BINOMEN

***Genus species subspecies* Author, year**

Original type species citation

Author, year, title, journal, page(s), [page of description].

Primary type (holotype/lectotype/syntypes)

Registration number, locality (latitude/longitude), collector(s) and collection date.

Secondary type(s) (paratype/paralectotype/allotype/possible paratypes) (number of types in WAM collection)

Registration number, locality.

Current nomenclature

Current generic and specific recognition of the species.

Current status

Current status and validity of the species, synonymies.

Remarks

Additional information provided on subjects including the history and status of types, location of additional type specimens and information regarding the synonymy or resurrection of a species or subspecies if necessary and available.

Each taxon is presented by the name provided by the original author(s), followed by the author's name, and year of publication. Species names are given in the exact format in which they were first published. The original type species publication citation follows next displaying the author(s), year, title (of article or book), journal (unless otherwise), page(s) and the page on which the species description commences in square brackets. Primary type (holotype, lectotype or syntype/s) information includes WAM registration number, locality, latitude and longitude (in degrees minutes seconds, where recorded to that precision), collector(s) name and collection date. Primary type localities and coordinates shown in quotes are those presented in the original published descriptions. Coordinates presented in square brackets that lack quotes are those that have been identified from accession data not presented in the original description or subsequently determined based on locality data presented in the description. All dates are presented as day – month – year, month – year, or year, as presented in the original description or relevant information sources. Secondary types (paratype/s, paralectotype/s and possible paratypes) are displayed showing WAM registration number and locality. Specific locality (latitude and longitude) and collection details (collector and date) are not provided for secondary type specimens. Possible paratypes are listed where it is clear additional specimens were included in the original description; however, no registration number was provided and only limited information was available. Where specimens that were likely to have been included matched data provided in the description but could not be confirmed, the species are recognised as possible paratypes. Specimens marked with an asterisk (*) are no longer held in the collection of the WAM, either due to gifting to another institution, disposal by WAM or loss of specimen. Details of specimens no longer held in the collection are discussed further in the Remarks section of each species where information was available. Current nomenclature and status are only presented where change from the original binomen has occurred, such as generic changes, specific amendments, changes to species or subspecies status and synonymy or resurrection from synonymy.

Remarks include relevant information on issues and errors from original descriptions, specimens, historical remarks or subsequent publications referring to the species or specimens as well as information relating to the synonymy or resurrection of the species or information pertaining to lost or destroyed specimens. Where call recordings from type material were used as part of the species description, the format, location and status of the recordings is presented where known. Where known, tissue samples for holotypes are presented with tissue type, storage method and storage location. Secondary type material with tissue samples deposited in the WAM are presented with tissue type and storage method where known. Tissue samples for type material that has been depleted is not presented. Square brackets indicate corrections or additions to information presented in the original description or subsequent publications. The prefix R is used to indicate that the registration number corresponds with the herpetofauna collection of the WAM.

Institution abbreviations follow Sabaj Pérez (2014) with the addition of the Arid Zone Research Institute, Alice Springs, Northern Territory, Australia (AZRI), Centre of Excellence in Natural Resource Management, University of Western Australia, Albany, WA (CENRM) and University of Western Australia, Crawley, WA, Australia (UWA). We have used the following abbreviations in presenting type information in this catalogue.

AMNH	American Museum of Natural History, New York, U.S.A.
AMS	Australian Museum, Sydney, New South Wales, Australia
AZRI	Arid Zone Research Institute, Alice Springs, NT, Australia (transferred into the NTM in 1985, see Horner 1999).
BMNH	Natural History Museum (formerly British Museum (Natural History)), London, England, U.K.
CAM	Central Australian Museum Alice Springs, NT, Australia (transferred into the NTM in 1985, see Horner 1999). Also referred to as Central Australian Wildlife Collection (CAWC).
CENRM	Centre of Excellence in Natural Resource Management, University of Western Australia, Albany, WA
the Code	the International Code of Zoological Nomenclature
E	east
EBU	Evolutionary Biology Unit, South Australian Museum, Adelaide, SA, Australia
ENE	east-northeast
ESE	east-southeast
HS	Homestead
Hwy	Highway
ICZN	International Commission for Zoological Nomenclature
Is	Island
km	kilometres

KU	University of Kansas Natural History Museum, Lawrence, Kansas, U.S.A.
MCZ	Museum of Comparative Zoology, Harvard University, Cambridge, Massachusetts, U.S.A.
mi	miles
MMUS	Macleay Museum, University of Sydney, New South Wales, Australia
Mt	Mount
N	north
NE	northeast
NMV	Museum Victoria (formerly National Museum of Victoria), Melbourne, Victoria, Australia
NNW	north-northwest
NP	national park
NR	nature reserve
nr	near
NT	Northern Territory, Australia
NTM	Museums and Art Galleries of the Northern Territory (formerly Northern Territory Museum of Arts and Sciences), Darwin, NT, Australia
NW	northwest
Qld	Queensland, Australia
QM	Queensland Museum, Brisbane, Qld, Australia
QVM	Queen Victoria Museum and Art Gallery, Launceston, Tasmania, Australia
Rd	Road
S	south
SA	South Australia, Australia
SAMA	South Australian Museum, Adelaide, SA, Australia
SE	southeast
SUM	Stellenbosch University, John R. Ellerman Museum of Zoology, Cape Town, South Africa
SSE	south-southeast
SSW	south-southwest
Stn	Station
SW	southwest
UWA	University of Western Australia, Crawley, WA, Australia
W	west
WA	Western Australia
WAM	Western Australian Museum, Perth, WA, Australia

ACCOUNT OF TYPE SPECIMENS

ANURA

Family Limnodynastidae

Heleioporus barycragus Lee, 1967

Lee, A.K. (1967) Studies in Australian Amphibia II. Taxonomy, ecology, and evolution of the genus *Heleioporus* Gray (Anura: Leptodactylidae). *Australian Journal of Zoology* **15**: 367–439 [390].

Holotype

R21869 (formerly UWA Zoology Department collection, A.R. Main field number 106/57), 'Boya, WA' [31°55'S, 116°03'E], A.K. Lee, 23 April 1957.

Paratypes

Not precisely known.

Possible paratypes (69)

R4425, Darkan, WA; R7004, R30422, R30529, R32793, R33066, R33171, R33357, R35159, Darlington, WA; R8453, nr Bullsbrook, WA; R11348, R11349*, R30413, Bickley, WA; R18562, R97588–90, 12 km E Kalamunda, WA; R19219, 6 mi [10 km] E Kalamunda, WA; R19646, Mundaring Weir, WA; R19821–22, 0.5 mi [0.8 km] S Pearce Aerodrome, WA; R21634–35, R30411–12, R30416, R30571, R33055, R33355–56, Boya, WA; R30409, R30417, R30421, R32491–93, R32781*, Caversham, WA; R30410, R32498, R32868, R33354, Swan View, WA; R30414, Greenmount–Red Hill Rd, WA; R30415, R32501, Sawyers Valley, WA; R30418, Red Hill Rd, WA; R30419, R33353, nr Boya, WA; R30420, Bakers Hill, WA; R30530, R32778, 4 mi [6 km] NE Beechina, WA; R32462, Beechina, WA; R32463, R32483–84, R35078–81, R35095–96, Red Hill, WA; R32481, R32650, John Forrest NP, WA; R32495, R32651–52, Middle Swan, WA; R33352, Greenmount, WA; R35052, Jarrahdale, WA; R38313, Walyunga Pool, WA; R97267, 1 mi [1.6 km] E Bullsbrook, WA.

Remarks

Holotype specimen has original the A.R. Main field tag still attached from when previously held by the UWA Zoology Department, 106/57. No paratypes were designated in the species description; however, Lee (1967) listed 38 specimens examined following the 'Description' and a further 64 specimens examined under 'Larvae and Juveniles', including broad localities and number of specimens examined from each category. Under 'Specimens examined' beneath the description heading, Lee (1967) stated 'Red Hill, 2 M, 1 F; Swan View, 1 M, 1F; Caversham, 3 M; Bakers Hill, 1 M; Sawyers Valley, 1 F; Darlington, 1 F; Greenmount 1; Boya, 18 M, 7 F; Bickley, 1 F'. Furthermore, under the Larvae and Juveniles heading, Lee lists an additional 64 specimens under specimens examined, including 'Larvae; Red Hill, 5; Greenmount, 46; Darlington, 2

Juveniles; Jarrahdale, 6; Red Hill, 6'. Article 72. (b) and Recommendation 73D of the then current first edition of the International Code of Zoological Nomenclature (ICZN 1961; Article 72.4.1 and 72.4.5 of the current fourth edition of the Code (ICZN 1999), the 102 (101 excluding holotype) specimens listed as examined are considered paratypes.

The WAM collection contains 69 specimens (excluding the holotype) that would have been available to Lee at the time of the description, including 57 (excluding the holotype) formerly from the UWA collection with the A.R. Main field numbers; however, it is not known which of the 69 specimens were included as specimens examined and all are currently maintained as possible paratypes. Of the 69 possible paratypes, various life stages of the species are represented with the exception of larvae and juveniles which are poorly represented in contrast to the number of specimens listed by Lee. Despite the low number of larvae and juvenile specimens, it is possible many of the specimens used for the description were allowed to grow to various life stages before being euthanised and subsequently deposited at the WAM. Most of the 69 possible paratypes have more precise locality data than those presented by Lee 1967; however, many occur within the broad localities listed by Lee. There are also additional specimens of other *Heleioporus* species with the A.R. Main field numbers from the same localities as the possible paratypes which may have also been examined if unknown identification errors occurred.

Of the 69 possible paratype specimens in the WAM collection, two could not be located and are considered lost, R11349 and R32781. One is listed as 'gifted' (R11349) and the other as 'disposed' (R32781) on the WAM database, both without date or explanation as to reason for disposal or which institution the gifted specimen was sent. All extant possible paratypes in the WAM collection are the whole specimens stored in 70% ethanol solution, with the exception of R11348 which is a dry complete skeletal specimen. The single skeletal specimen was part of a series of whole specimens stored in 70% ethanol which were sent to the University of Adelaide in 1978 and were subsequently skeletonised and returned to WAM in 2014.

Heleioporus inornatus Lee & Main, 1954

Lee, A.K. and Main, A.R. (1954) Two new species of burrowing frogs of the genus *Heleioporus* Gray from south-western Australia. *Western Australian Naturalist* **4**(7): 156–158 [157].

Holotype

R11428 (formerly UWA Zoology Department collection, A.R. Main field number 155/54), 'Beechina, WA' [31°49'S, 116°20'E], A.R. Main, 29 April 1954.

Paratypes (20)

Unknown.

Possible paratypes (31)

R21638–39, R32994, Beechina, WA; R30536, R30538, R32433, R32434, R32436, R32962, R32965–68, R32973–74, R32976, R33054, R35009, R35075, R35083–84, R35089, R35121, 31 mi [50 km] peg, Perth–Northam Rd [Great Eastern Hwy], WA; R32429, R32438, R32975, Sheepwash Creek, WA; R32435, 10 mi [16 km] E Dwellingup, WA; R32437, 8 mi [13 km] E Pinjarra, WA; R32439, 11 mi [18 km] E Pinjarra, WA; R32440, Sawyers Valley, WA; R33169, Gleneagle, WA.

Remarks

The holotype specimen was formerly held in the UWA Zoology Department collection prior to being deposited at the WAM (Anonymous 1961; Lee and Main 1954). In the early WAM hardcopy specimen register, the registration entry annotated with the A.R. Main field number 155/54 is R32675; however, the field tag is attached to the specimen registered as R11428. The specimen associated with the registration R32675 is *H. eyrei* from the '31 m peg, Perth–Northam Road, Beechina' and a loose tag (detached from specimen) with the A.R. Main field number 81/54 can be matched to the specimen which has the string from the former field tag still attached.

No paratypes were designated in the species description; however, Lee and Main present average snout to cloaca measurements based on 18 males and 2 female specimens but do not provide any additional information on the specimens. Under Article 72.4.1 and 72.4.5 of the International Code of Zoological Nomenclature (ICZN 1999), the 20 (19 if holotype excluded) additional specimens are considered paratypes. Lee and Main mention that material used in the description was part of the UWA collection to be transferred to the WAM.

The WAM collection contains 36 specimens (excluding the holotype) that would have been available to Lee and Main at the time of the description, including 31 (excluding the holotype) formerly from the UWA collection with the A.R. Main field numbers; however, it is not known which of the 31 specimens were included as specimens examined and all are currently maintained as possible paratypes. There are multiple specimens of other *Heleioporus* species with the A.R. Main field numbers from the same localities as the possible paratypes which may have also been examined if unknown identification errors occurred. All but two possible paratypes are whole specimens stored in 70% ethanol solution, R32965–66 are dry skeletal specimens. The two skeletal specimens were formerly whole specimens stored in 70% ethanol which were sent to the University of Adelaide in 1978 and were subsequently skeletonised and returned to WAM in 2014.

Heleioporus insularis Loveridge, 1933

Loveridge, A. (1933) A new genus and three new species of crinine frogs from Australia. *Occasional Papers of the Boston Society of Natural History* **8**: 89–94 [92].

Holotype

R4303, 'Rottnest Island, WA' [32°00'S, 115°31'E], L. Glauert, collection date unknown.

Paratype

R4289, Rottnest Is, WA.

Current status

Junior synonym of *Heleioporus eyrei, fide* Parker (1940) and Cogger et al. (1983).

Remarks

Five additional paratype specimens are in the MCZ: MCZ 18198–202.

Heleioporus psammophilus Lee & Main, 1954

Lee, A.K. and Main, A.R. (1954) Two new species of burrowing frogs of the genus *Heleioporus* Gray from south-western Australia. *Western Australian Naturalist* **4**(7): 156–158 [157].

Holotype

R11427 (formerly UWA Zoology Department collection, A.R. Main field number 364/54), 'Beechina, WA' [31°49'S, 116°20'E], A.R. Main, 6 May 1954.

Paratypes (20)

Unknown.

Possible paratypes (38)

R21640, R30510, Beechina, WA; R30511–13, R30515, R30517, R30519–23, R30525–26, R30528, R32963, R32969, R32982–83, R32984*, R32985*, R32986*, R32987, R32989 31 mi [50 km] peg, Perth-Northam Rd [Great Eastern Hwy], WA; R30514, Walpole, WA; R30516, 257 mi [414 km] peg, Perth–Geraldton Rd [Brand Hwy], WA; R30518, R32960, Sheepwash Creek, WA; R30524, R32961, R32990, Swan View, WA; R30527, R32993, 257 mi [414 km] peg, Dongara-Mingenew Rd [Midlands Rd], 15 mi [24 km] E Dongara, WA; R32849, Roes, WA; R32964, 31 mi [50 km, in error] past Sheepwash Creek, WA; R32991, R33292, Lake Dalaroo, WA; R33168, Chidlow, WA.

Remarks

The holotype specimen was formerly held in the UWA Zoology Department collection prior to being deposited at the WAM (Anonymous 1961; Lee and Main 1954). No paratypes were designated in the species description; however, Lee and Main present average snout to cloaca measurements based on 18 males and 2 female specimens but do not provide any additional information on the specimens. Under Article 72.4.1 and 72.4.5 of the International Code of Zoological Nomenclature (ICZN 1999), the 20 (19 if holotype excluded in meristic data provided in the description) additional specimens are considered paratypes. Lee and Main mention that material used in the description was part of the UWA collection to be transferred to the WAM.

The WAM collection contains 38 specimens (excluding the holotype) with collection dates from 1954 or earlier, all of which were collected by Lee or Main and were formerly in the UWA collection with the A.R. Main field numbers; however, it is not known which of the 38 specimens were included as specimens examined and all are currently maintained as possible paratypes. With the exception of two specimens (R32982–83), all possible paratypes are whole specimens stored in 70% ethanol solution, R32982–83 dry skeletal specimens. Both skeletal specimens are formerly whole specimens stored in 70% ethanol sent to the University of Adelaide in 1978 which were subsequently skeletonised and returned to WAM in 2014. One possible paratype specimen (R32985) is listed as destroyed on the WAM database with no additional information or reasoning provided. Two possible paratype specimens (R32984 and R32986) are listed as missing on the WAM database and have not been sighted since May 1998; both specimens could not be located and are presumed lost.

Limnodynastes depressus Tyler, 1976

Tyler, M.J. (1976) A new genus and two new species of leptodactylid frogs from Western Australia. *Records of the Western Australian Museum* **4**(1): 45–52 [50].

Holotype

R43896, 'near former Argyle Downs homestead, Ord River, WA' [16°17'S, 128°48'E], Western Australian Museum survey party, 12 January 1972.

Remarks

A tag associated with the type specimen states collection as 'vicinity of old Argyle Downs Homestead, Ord River, WA'. The type specimen was collected as part of 'Operation Noah' when the waters began to rise at the completion of the Ord River dam in 1971, forming Lake Argyle (Ron Johnstone, personal communication, 2016). The type location is currently completely submerged below the lake.

Megistolotis lignarius Tyler, Martin & Davies, 1979

Tyler, M.J., Martin, A.A. and Davies, M. (1979) Biology and systematics of a new limnodynastine genus (Anura: Leptodactylidae) from north-western Australia. *Australian Journal of Zoology* **27**: 135–150 [137].

Holotype

R58299, 'adjacent to the Lake Argyle-Kununurra road, 6.5 km N. of Lake Argyle Tourist Village, Lake Argyle, Kimberley Division, WA' [16°02'S, 128°47'E], M. Davies, A.A. Martin and M.J. Tyler, 20 February 1977.

Paratypes (3)

R42398, Kalumburu, WA; R50891, Drysdale River NP, WA; R58881, 5.2 km S Beta Creek, WA.

Current nomenclature

Limnodynastes lignarius, see Schäuble et al. (2000).

Remarks

Additional paratype specimens are held in other collections: 15 at SAMA (SAMA R16228–29, R16316–25, R16377, R16608–09), seven at NTM (including 2 formerly from AZRI-CAM collection; NTM R578–79, R642, R2143, R5035, R31043 (formerly AZRI-CAM A121), R31044 (formerly AZRI-CAM A122), four at AMS (AMS R38999–9000, R46127, R61485), one at BMNH (BMNH 1977.517) and one at KU (KU 175514) (Tyler et al. 1979).

Neobatrachus albipes Roberts, Mahony, Kendrick & Majors, 1991

Roberts, J.D., Mahony, M., Kendrick, P. and Majors, C.M. (1991) A new species of burrowing frog, *Neobatrachus* (Anura: Myobatrachidae), from the eastern wheatbelt of Western Australia. *Records of the Western Australian Museum* **15**(1): 23–32 [24].

Holotype

R101178 [in error, R101182], '4.2 km N Hopetoun, WA (33°54'S, 120°08'E)', J.D. Roberts and P. Kendrick, 3 May 1988.

Paratypes (15)

R36291, 41.6 km E Southern Cross, WA; R39841, Greenshield Soak, nr Lake Magenta, WA; R49800, Dongolocking NR, WA; R52546, R52550, Badjaling NR, 11 km E Quairading, WA; R65144, 0.6 km W Lake Cronin, WA; R93378, Junana Rock, Cape Arid NP, WA; R94796, Lake Magenta NR, WA; R96779, Fitzgerald River NP, WA; R101179–80, R101185, 20.5 km E Jerramungup, WA; R101183–84, Pallarup Rocks, 44.6 km NE Ravensthorpe, WA; R101186, Yoting, WA.

Remarks

The holotype (R101178) listed by Roberts et al. (1991) is in error; R101178 is a specimen of *Neobatrachus pelobatoides* collected from 20.5 km W Jerramungup, WA and does not match the morphological description given for *N. albipes* (Roberts 2010). Roberts (2010) determined the true holotype for *N. albipes* as specimen R101182 which correctly matched the morphology and locality presented in the description, identified by the call recording collected in the field for the holotype (Frog #3, JDR Tapes 79 and 80). Holotype calls recorded and described in the species description (Frog #3, JDR Tapes 79 and 80) are currently housed in the CENRM. Liver sample of one paratype (R101180) stored at the EBU.

Neobatrachus aquilonius Tyler, Davies & Martin, 1981

Tyler, M.J., Davies, M. and Martin, A.A. (1981) New and rediscovered species of frogs from the Derby–Broome area of Western Australia. *Records of the Western Australian Museum* **9**(2): 147–172 [155].

Holotype

R71005, '22–41 km S of Derby, Kimberley Division, WA' [17°30'S, 123°44'E], A.H. Cross, M. Davies, A.A. Martin and M.J. Tyler, 14 February 1980.

Paratypes (9)

R62195, 32 km S Derby, WA; R71001–04, R71006–09, 10–41 km S Derby, WA.

Remarks

Of the additional eight paratypes presented in the description, seven are in SAMA (SAMA R18012–14, R18032–33, R18101–02) and one in BMNH (BMNH 1979.729).

Neobatrachus fulvus Mahony & Roberts, 1986

Mahony, M.J. and Roberts, J.D. (1986) Two new species of desert burrowing frogs of the genus *Neobatrachus* (Anura: Myobatrachidae) from Western Australia. *Records of the Western Australian Museum* **13**(1): 155–170 [157].

Holotype

R52994, 'Exmouth, near North West Cape, WA (21°56'S, 114°07'E)', G. Harold and G. Barron, 8 March 1976.

Paratypes (10)

R52937–42, Exmouth, WA; R76583, 18 km E Gnaraloo, WA; R93494–96, Learmonth, WA.

Remarks

Two additional paratypes are held in AMS: AMS R119438–39. A loose label associated with the holotype states '*Neobatrachus centralis,* collected by G. Harold and G. Harold [in error, G. Barron] from Exmouth light aircraft landing strip'. Call structure for this species reported in the type description was from a single frog on a cassette recording – details reported in Mahony and Roberts (1986). Current status of original recording is unknown.

Neobatrachus kunapalari Mahony & Roberts, 1986

Mahony, M.J. and Roberts, J.D. (1986) Two new species of desert burrowing frogs of the genus *Neobatrachus* (Anura: Myobatrachidae) from Western Australia. *Records of the Western Australian Museum* **13**(1): 155–170 [163].

Holotype

R93485, '8.9 km S of Merredin, WA (31°33'S, 118°15'E)', J.D. Roberts and D. Cale, 26 May 1985.

Paratypes (8)

R93486–92, 7–18 km S Merredin, WA; R93493, 15.1 km SSW Narembeen, WA.

Remarks

Three additional paratypes are held in AMS: AMS R119436–37 and R118104. The holotype and six WAM paratypes were previously held in AMS but were not formally registered with the AMS R prefix. The former AMS specimens have A.M. herpetology field (A.M. Herp) numbers still attached; holotype R93485 (formerly A.M. Herp 35694) and paratypes R93486 (A.M. Herp 35672), R93487 (A.M. Herp 35681), R93488 (A.M. Herp 35682), R93489 (A.M. Herp 35695), R93490 (A.M. Herp 35691), R93491 (A.M. Herp 35692) and R93492 (A.M. Herp 35693). Mahony and Roberts (1986) stated 'call data are available from two paratypes and from two other frogs' and provided a description of the species mating call, supplemented with an oscillogram. Of the eight paratypes, five are males and it is not known which individuals the call recordings are associated with.

Neobatrachus sutor Main, 1957

Main, A.R. (1957) A new burrowing frog from Western Australia. *Western Australian Naturalist* **6**(1): 23–24 [24].

Holotype

R32892 (formerly UWA Zoology Department collection, A.R. Main field number 22/57), 'Gnoolowa Hill, 18 miles [29 km] north of Mingenew', WA [28°54'S, 115°26'E], A.R. Main, 18 March 1957.

Paratype

R32893 (formerly UWA Zoology Department collection, A.R. Main field number 21/57), Gnoolowa Hill, 18 miles [28.9 km] N Mingenew, WA.

Remarks

Holotype and allotype (now considered a paratype) formerly held in the Zoology Department Collection, University of Western Australia, registration numbers 22/57 (R32892) and 21/57 (R32893) prior to being transferred to the WAM. Western Australian Museum registration numbers were identified from examination of accession data for the two specimens matching Main's specimen field numbers given in the description. The allotype specimen listed by Main (R32893) is considered a paratype here under Article 72.4.6 of International Code of Zoological Nomenclature (ICZN 1999).

Notaden weigeli Shea & Johnston, 1988

Shea, G.M. and Johnston, G.R. (1988) A new species of *Notaden* (Anura: Leptodactylidae) from the Kimberley Division of Western Australia. *Transactions of the Royal Society of South Australia* **112**: 29–37 [29].

Holotype

R77149, 'Sandstone Ck [in error, Camp Ck, Mitchell Plateau], WA (14°53'30"S, 125°45'00"E)', C. Kemper, 26 October 1981.

Paratypes (3)

R83428–29, 23 km NW old Mount Elizabeth HS, WA; R100216 (formerly AMS R123896), Mitchell Plateau, WA.

Remarks

The 1987 publication date listed in the citation summary at the beginning of the paper is in error; the correct publication data is 31 May 1988 as stated at the end of the citation summary. The holotype locality of Sandstone Creek is in error; the specimen was in fact collected from Camp Creek, Mitchell Plateau. 'Sandstone Creek' was in reference to the description of the collection site which was also provided when the specimen was accessioned (Laurie Smith, personal communication, 2016). The incorrect locality information was erroneously presented on specimen loan documentation provided to the author and subsequently presented in the description (Glenn Shea, personal communication, 2016). One paratype formerly held at AMS (AMS R123896) was gifted to WAM following the description (R100216). A further three paratypes are held in AMS: AMS R123897–99.

Family Myobatrachidae

Arenophryne rotunda Tyler, 1976

Tyler, M.J. (1976) A new genus and two new species of leptodactylid frogs from Western Australia. *Records of the Western Australian Museum* **4**(1): 45–52 [46].

Holotype

R39120, '100 m from False Entrance Well Tank, Carrarang Station, 320 km NNW of Geraldton, WA (26°23'S, 113°18'E)', A. Baynes and T.A. Smith, 24 August 1970.

Paratypes (8)

R39115–19, R39121–23, False Entrance Well, Carrarang Stn, WA.

Remarks

Tags associated with the holotype initialled with M.J.T. state '*Arenophryne globosa*' (the previous working name; Michael Tyler, personal communication, 2016) with collection data as presented in the description; however, it is dated '22:VIII:1970'. An additional paratype is held in SAMA (SAMA R14521).

Arenophryne xiphorhyncha Doughty & Edwards, 2008

Doughty, P. and Edwards, D. (2008) A new species of *Arenophryne* (Anura: Myobatrachidae) from the central coast of Western Australia. *Records of the Western Australian Museum* **24**: 121–131 [122].

Holotype

R67321, 'Cooloomia Station, WA (27°01'S, 114°19'E)', J. Rolfe, S.D. Hopper, P.J. Fuller and K. Cashin, 19 September 1979.

Paratypes (10)

R67320, R67323, Cooloomia Stn, WA; R123485, R123554, R126245, R126251, R126261, R126270, 50 km N Kalbarri, WA; R165815, Sandy Junga Pits, WA; R165821, 10 km NW Murchison House Stn, WA.

Remarks

Liver sample of two paratypes (R165815, R165812) stored in 100% ethanol solution at the WAM.

Crinia fimbriata Doughty, Anstis & Price, 2009

Doughty, P., Anstis, M. and Price, L.C. (2009) A new species of *Crinia* (Anura: Myobatrachidae) from the high rainfall zone of the northwest Kimberley, Western Australia. *Records of the Western Australian Museum* **25**: 127–144 [137].

Holotype

R167743, 'Little Mertens Falls, Mitchell Plateau, WA (14°49'20"S, 125°42'39"E)', L. Price and J. Francis, 7 January 2007.

Paratypes (8)

R163823, 5.2 km SW Prince Regent River and Pitta Creek Junction, WA; R167744–45, Little Mertens Falls, Mitchell Plateau, WA; R159800–02, R159803*, Mitchell Plateau, WA; R159804, Prince Regent River NR, WA.

Remarks

Registration numbers were allocated to some paratype specimens in life that were maintained in captivity for a period for the description. R159803 was a tadpole that died in captivity and became partially decomposed. After preservation it was in poor condition and was disposed of. Despite being listed as a paratype, this specimen was not included in the individuals examined that formed the descriptions (Marion Anstis, personal communication, 2016). Of the seven paratypes in the WAM collection, three are adult or metamorph specimens (R163823, R167744, R167745) and four are larvae (R159800–02, R159804). One additional paratype is held in SAMA (SAMA R62994). Liver sample of the holotype and three paratypes (R163823, R167744–45) stored in 100% ethanol solution at the WAM.

Crinia glauerti Loveridge, 1933

Loveridge, A. (1933) Four new crinine frogs from Australia. *Occasional Papers of the Boston Society of Natural History* **8**: 55–60 [57].

Paratype

R4583*, Mundaring Weir, WA.

Remarks

Under paratypes, Loveridge (1933) listed registration numbers of two specimens from the MCZ collection (MCZ 18421–22) and stated two additional specimens were donated to the WAM and AMS (AMS R10910), both with the same collection details as the holotype. Holotype housed in the MCZ collection: MCZ 18420, from 'Mundaring Weir, about thirty miles [48 km] northeast of Perth, West Australia' [31°57'S, 116°09'E], collected by P.J. Darlington, 22 November 1931. The paratype could not be located and has not been sighted in audits dating back to October 1998; the specimen is presumed lost.

Crinia lutea Main, 1963

Main, A.R. (1963) A new species of *Crinia* (Anura; Leptodactylidae) from National Park, Nornalup. *Western Australian Naturalist* **8**(6): 143–144 [143].

Holotype

R17616, 'shallow valley on left bank of Deep River on western boundary of Nornalup National Park [Walpole Nornalup National Park], where the Manjimup to Denmark road enters the park', WA [34°59'S, 116°38'E], A.R. Main, 23 October 1962.

Paratypes (9)

Unknown*, Deep River, WA.

Current nomenclature

Geocrinia lutea, see Blake (1973).

Remarks

No paratypes were designated in the species description; however, Main states 'Other specimens examined; males 2, females 2, juv. 4' in the text and mentions multiple collecting events at the type locality in the introduction. Under Article 72. (b) and

Recommendation 73D of the then current first edition of the International Code of Zoological Nomenclature (ICZN 1961; Article 72.4.1 and 72.4.5 of the current fourth edition of the Code (ICZN 1999), the nine additional specimens are considered paratypes. No additional specimens matching the collection or locality data presented in the original description could be located in the WAM collection and all nine paratypes are considered lost.

Crinia parinsignifera Main, 1957

Main, A.R. (1957) Studies in Australian Amphibia 1. The genus *Crinia* Tschudi in south-western Australia and some species from south-eastern Australia. *Australian Journal of Zoology* **5**: 30–55 [53].

Holotype

R38735 (formerly UWA Zoology Department collection, A.R. Main field number 431/55), 'Kingston-on-Murray', SA, [34°14'S, 140°21'E], A.R. Main, 18 August 1955.

Paratypes (9)

R38245, R38728, R38733, R38736, R38738–39, Kingston-on-Murray, SA; R38730, R38734, R38737, 7 mi [11 km] N Horsham, Vic.

Remarks

Holotype formerly held in the Zoology Department Collection, UWA, with the A.R. Main field tag (431/55) prior to being transferred to WAM. No paratypes were designated in the species description; however, Main lists 25 specimens under specimens examined from Blanchetown, SA (1), Kingston-on-Murray, SA and 7 miles north of Horsham, Vic. but does not provide any additional information on these specimens. Under Article 72. (b) and Recommendation 73D of the then current first edition of the International Code of Zoological Nomenclature (ICZN 1961; Article 72.4.1 and 72.4.5 of the current fourth edition of the Code (ICZN 1999), the 25 (24 if holotype excluded) additional specimens are considered paratypes. Main stated that all examined material was collected by himself and held in the UWA Zoology Department collection. He did not indicate if all specimens were deposited at WAM or some were maintained at UWA.

Of the 24 specimens (excluding the holotype) listed as examined by Main, only nine specimens matching the locality data are held in the WAM collection, six from Kingston-on-Murray, S.A. and three from 7 miles north of Horsham, Vic. No specimens associated with the locality Banchetown, SA could be located; however, it is not known if these and the remaining 15 specimens listed by Main were deposited at the WAM or another institution and their current whereabouts are unknown. The 15 additional paratypes that cannot be located are presumed lost.

Crinia pseudinsignifera Main, 1957

Main, A.R. (1957) Studies on Australian Amphibia 1. The genus *Crinia* Tschudi in south-western Australia and some species from south-eastern Australia. *Australian Journal of Zoology* **5**: 30–55 [52].

Holotype

R36153 (formerly UWA Zoology Department collection, A.R. Main field number 1000/54), 'Yorkarakine Rock, 15 miles [24 km] north of Tammin, WA' [31°25'S, 117°31'E], A.R. Main, 19 July 1954.

Paratypes (233)

Unknown, Nebree Spring, WA (N = 3); Koodiwoodie, WA (N = 16); Dongara, WA (N = 7); Chittering, WA (N = 7); Bullsbrook, WA (N = 3); Red Hill, WA (N = 3); Walyunga, WA (N = 3); Helena Valley, WA (N = 8); Mundaring, WA (N = 5); Darlington, WA (N = 3); Boya Quarry, WA (N = 22); Beechina, WA (N = 42); Clackline, WA (N = 1); Northam, WA (N = 1); Quairading, WA (N = 7); Waeel, WA (N = 1); Yorkrakine Rock, WA (N = 21); Moorine Rock, WA (N = 3); Kwolyin, WA (N = 18); 217 mi [349 km] post, Albany Rd [Hwy], WA (N = 3); Lake Muir, WA (N = 5); Yallingup turnoff, Dunsborough, WA (N = 1); Augusta-Nannup Rd, WA (N = 15); Stirling Ranges, WA (N = 15); 8 mi [13 km] E Jarramongup [Jerramungup], WA (N = 2); Peak Charles, WA (N = 2); Doubtful Island Bay, WA (N = 1); 18 mi [29 km] W Ravensthorpe, WA (N = 5); 5 mi [8 km] E Ravensthorpe, WA (N = 1); Junana Rock and Pine Hill, WA (N = 5); Dempster's Head, Esperance, WA (N = 4).

Possible paratypes (229)

R825–26, Moingup Pass, Stirling Range, WA; R968–72, R39263, R39349, Darlington, WA; R1912–14, Lower Chittering, WA; R30269, R38677–78, R39307, R39316, R39354, Beechina, WA; R34900, R35913–20, R38746, R38749, R39260, R39272, Stirling Range, WA; R35362–66, R35848, R35396, Koodiwoodie Creek, Dandaragan, WA; R35385, R35430, R38807–09, R39309–10, R39323, R39326–28, R39330–34, R39336–48, R39350, R39353, R39356–58, R39398, 31 mi [50 km] peg, Perth–Northam Rd, Beechina, WA; R35693, R39373–74, Moorine Rock, WA; R35961–64, Junana Rock, WA; R35965, Pine Hill, WA; R38210, R38663, R39368, Helena Valley, WA; R38211–16, Red Hill Rd, WA; R38241, R38628, R38656–57, Peak Charles, WA; R38246,0.5 mi [0.8 km] W Lake Muir, WA; R38498*, Yorkrakine Hill, WA; R38632–34, R38643–45,18 mi [29 km] W Ravensthorpe turnoff, WA; R38648–54, R38658, R38659–61, R39433, Dempster's Head, Esperance, WA; R38664, R38666–70, Koodiewoodie, WA; R38745, 116 mi [187 km] peg, Albany Hwy, WA; R38748, R39255–56, R39267, R39269, 6 km SE Toolbrunup Peak, Stirling Range NP, WA; R38788–805, R38806*, Kwolyin, WA; R38810–14, R38817–21, R39335, R39351, R39359–64, Yorkrakine Rock, WA; R38822, R39311–14, R39322, R39385, R39387–91, Augusta–Nannup Rd, WA; R39251–54, Chittering

Brook, WA; R39261, Swamp SE of Chittering Pass, WA; R39278, Chittering Lakes, WA; R39281, nr Yallingup turnoff, Dunsborough, WA; R39282, 5 mi [8 km] E Ravensthorpe, WA; R39283–97, quarry at Boya, WA; R39298–300, Quairading, WA; R39303, Northam, WA; R39304–05, 8 mi [13 km] E Jerramungup, WA; R39306, R39366–67, R39370–72, Irwin River, Dongara, WA; R39315, R39324, Albany Hwy, Kendenup, WA; R39318–21, Quairading Spring, WA; R39329, Clackline, WA; R39352, Waeel, WA; R39355, R39369, Red Hill, WA; R39365, Doubtful Island Bay, WA; R39378–81, Mundaring, WA; R39382–84, R39386, Dammed Creek, Helena Valley, WA.

Remarks

Holotype formerly held in the Zoology Department collection, UWA, with the A.R. Main field tags attached (1000/54) prior to being transferred to WAM. No paratypes were designated in the species description; however, Main lists 234 specimens (presumably including the holotype) from 32 localities under specimens examined (p. 52), see above for localities and number of the specimens from each with one specimen from Yorarakine Rock (presumably holotype) excluded. In accordance with Article 72.4.1 and 72.4.5 of the current fourth edition of the Code (ICZN 1999), the 234 (233 if holotype excluded) additional specimens are considered paratypes. Main did not state if specimens examined would be deposited at the WAM and it is not known if all specimens were subsequently deposited at the WAM, other institutions or disposed of following the description.

A total of 337 specimens in the WAM collection from various locations would have been available to Main for the description, of which 229 match locality data presented in the description including 178 collected by Main. The WAM collection holds 47 specimens matching the localities and associated number of specimens presented by Main for 14 localities from; Nebree Spring (N = 3), Clackline (N = 1), Northam (N = 1), Quairading (N = 7), Waeel (N = 1), Moorine Rock (N = 3), Kwolyin (N = 18), 217 mi [349 km] post Albany Rd [Hwy] (N = 3), Yallingup turnoff, Dunsborough (N = 1), 8 mi [13 km] E Jerramungup (N = 2), Doubtful Island Bay (N = 1), 5 mi [8 km] E Ravensthorpe (N = 1), Juana Rock and Pine Hill (N = 5). The WAM collection also holds more than the number of specimens listed by Main for some locality records including Chittering, Red Hill, Darlington, Stirling Ranges, Peak Charles, 18 mi [29 km] W Ravensthorpe and Dempster's Head, Esperance. As the specific specimens examined by Main cannot be identified, all specimens are maintained as possible paratypes. The number of specimens in the WAM collection matching some localities listed by Main does not total the number of specimens associated with each listed by Main; Koodiwoodie (10 of 16), Dongara (6 of 7), Bullsbrook (0 of 3), Walyunga (0 of 3), Helena Valley (7 of 8), Mundaring (4 of 5), Boya Quarry (15 of 22), Beechina (41 of 42), Yorkrakine Rock (20 of 22), Lake Muir (1 of 5), Augusta–Nannup Rd (12 of 15). As it is not known which, if any, of the specimens held in the WAM collection matching the locality data presented by Main are in fact specimens examined by Main, all specimens are currently maintained as possible paratypes. The additional specimens of some localities referred to by Main that could not be identified or located in the WAM collection are presumed lost. Two possible paratypes, R38498 and R38806, could not be located and have not been sighted in audits dating back to July 1998; both specimens are presumed lost.

Crinia rosea Harrison, 1927

Harrison, L. (1927) Notes on some Western Australian frogs, with descriptions of two new species. *Records of the Australian Museum* **15**: 277–287 [279].

Paratypes

Unknown.

Current nomenclature

Geocrinia rosea, see Blake (1973).

Remarks

Harrison (1927) reported eight individuals used in the description, all collected from the type locality 'Pemberton, in Karri country, 218 miles [351 km] south of Perth', WA [34°26'S, 116°03'E], 28 August 1926. In the description for the species under '*Types*' Harrison states 'Holotype female and allotype male in the Macleay Museum of the University of Sydney. Paratype material will be distributed to the Western Australian Museum, Perth, the Australian Museum, Sydney, the British Museum (Natural History), and the American Museum of Natural History.' However, there are no specimens in the WAM collection matching the type information provided, or any record of specimens being received by the WAM.

Shea and Sadlier (1999) reported there was no evidence that type specimens of *C. rosea* were received or held in the collection of MMUS, AMS or WAM and Cogger et al. (1983) reported syntypes not found for this or the other species described in the same publication (*Pseudophryne nichollsi* Harrison, 1927). In Parker's (1940) monograph on leptodactylid frogs, he lists a single specimen examined: MCZ 18419 from the type locality; however, the specimen is part of a series collected by P.J. Darlington in 1931 (Loveridge 1935) and postdates the species description. Cogger (1979) stated primary herpetological types of the MMUS were given to the AM on permanent loan in 1969; however, no types for *C. rosea* were listed.

In a list of herpetological type specimens in the MMUS, Goldman et al. (1968) list seven amphibian types; however, this does not include types for *C. rosea* or *Pseudophryne nichollsi* Harrison, 1927 and there is no mention of the species at all. Goldman et al. (1968) stated 'several types appear to have been lost' which was attributed to the museum's history within the Macleay Building. Namely, as a result of the collection being moved on multiple occasions to various parts of the Macleay Building, including a period during which it was sealed in the attic, and periods where the collection often suffered from a lack of access and inadequate management (Glenn Shea, personal communication, 2016). During periods of inadequate curatorship many specimens in spirit preservative, particularly amphibians and reptiles, dried out (Goldman et al. 1968; Horning 1993; van der Valk 1984). In a later catalogue of the amphibian specimens in the MMUS (van der Valk 1984), there is also no mention of *C. rosea* or *Pseudophryne nichollsi*.

There is no record or evidence of any type specimens of *C. rosea* at the AMS (Shea and Sadlier 1999; Glenn Shea, personal communication, 2016), AMNH (David Dickey, personal communication, 2016) or BMNH (Jeff Streicher, personal communication, 2016). Parker (1940) made no reference to any specimens matching the information for types provided by Harrison in a subsequent publication on Australian frogs. Numerous searches of WAM specimens and records including accession data have failed to locate any evidence of any type specimens for the species. It is likely the specimens were never deposited or distributed to any of the museums listed in the description, and were instead disposed of or lost following Harrison's unexpected death only a year after the description of *C. rosea* and *P. nichollsi* in early 1928 (Glenn Shea, personal communication, 2016).

Crinia subinsignifera Littlejohn, 1957

Littlejohn, M.J. (1957) A new species of frog of the genus *Crinia*. *Western Australian Naturalist* **6**(1): 18–23 [22].

Holotype

R12786 (formerly UWA Zoology Department collection, A.R. Main field number 367/56), 'swamps by the 181 mile peg on the main Perth to Pemberton road at Wilgarup, 7 mi [11 km] north of Manjimup', WA [34°08'S, 116°10'E], M.J. Littlejohn, 14 July 1956.

Paratypes (34)

Unknown, Wilgarup, WA (N = 15); 15 miles [24 km] N Mt. Barker Warriups Rd. [in error] (N = 8); [Warriup Rd.,] 4 miles [6 km] E Cheyne Beach turn-off (N = 12).

Possible paratypes (25)

R38958–66, 181 mi [291 km] peg, Wilgarup, WA; R39209–24, 1 mi [1.6 km] W Warriup Rd. turnoff, WA.

Remarks

A label associated with the holotype reads 'M.T. Littlejohn' as source and '14.7.1956' as collection date. Holotype formerly held in the collection of the UWA Zoology Department, the A.R. Main field number 367/56 prior to being transferred to WAM (Anonymous 1961; Littlejohn 1957). Call recordings of the holotype specimen were collected and described in the species description. An analogue recording (tape) and oscillograms of the recording were deposited with the holotype; however, neither recordings nor oscillograms could be located after the 2004 move of collections and are considered lost. In referring to the type specimens, Littlejohn states 'to be transferred to the Western Australian Museum'; however, there is no mention of any other material examined being deposited at the WAM.

No paratypes were designated in the species description; however, Littlejohn presents body lengths for 35 specimens (presumably including the holotype) from 'Waligarup' (N = 15), '15 miles [24 km] north of Mt. Barker Warriups Rd., [in error]' (N = 8) and '[Warriup Rd.], 4 miles [6 km] east of Cheyne Beach turn-off' (N = 12) but does not provide any additional information regarding specimens. One locality presented by Loveridge '15 miles [24 km] north of Mt. Barker Warriups Rd.,' is in error; 'Warriups [Warriup] Rd.,' is associated with the following locality '4 miles [6 km] east of Cheyne Beach turn-off'. In accordance with Article 72.4.1 and 72.4.5 of the fourth edition of the Code (ICZN 1999), the 34 (35 if holotype included) additional specimens are considered paratypes. The WAM collection contains 25 specimens (excluding the holotype) closely matching locality data presented in the description that would have been available to Littlejohn at the time of the description, including 16 (excluding the holotype) formerly from the UWA collection; however, it is not known which of the 25 specimens were included as specimens examined and all are currently maintained as possible paratypes. Of the 25 specimens in the WAM collection, 16 are from '1 mi [1.6 km] W Warriup turnoff, WA' and nine from '181 mi [291 km] peg, Wilgarup, WA'. No specimens associated with the locality '15 miles north of Mt. Barker' could be located; however, it is not known if these and other specimens examined by Littlejohn were deposited at the WAM, another institution or possibly disposed of and their current whereabouts are unknown. Nine of the additional specimens referred to by Littlejohn that could not be identified or located are presumed lost. There are also additional specimens of other *Crinia* species collected by Littlejohn from the same localities as the possible paratypes which may have also been examined if unknown identification errors occurred.

Geocrinia alba Wardell-Johnson & Roberts, 1989

Wardell-Johnson, G. and Roberts, D. (1989) Endangered! Forest frogs. *Landscope* **5**(1): 17 [17].

Lectotype

R94466, 'Bruce Road, 11.5 km S of Witchcliffe, WA (34°03'S, 115°10'E)', G. Wardell-Johnson and J.D. Roberts, 15 November 1985.

Paralectotypes (18)

R94457*, R95955–62, R95964–72, Bruce Road, 11.5 km S Witchcliffe, WA.

Remarks

The species, along with *G. vitellina*, was first presented as a new species with diagnostics (ventral colouration) to diagnose them from their congeners by Wardell-Johnson and Roberts (1989) in the popular glossy-paged magazine *Landscope* published by the Department of Conservation and Land Management (now Department of Parks and Wildlife). Because a name was proposed accompanied by diagnostic characters, this was sufficient at the time to qualify as a valid description in zoology under the International Code of Zoological Nomenclature, then third edition (ICZN 1985). This was not known by the senior author due to the differences in valid description criteria between the International Code of Zoological Nomenclature and the International Code of Botanical Nomenclature, the author's area of expertise. A holotype was not nominated in the magazine article; thus no information was provided on the type series. The 'original description' was focused on 'drawing attention to their urgent need for conservation' and not to provide a full description of the species (Roberts et al. 1990). An extended description and nomination of type specimens was presented by Roberts et al. (1990) where they listed the intended type series and designated a lectotype. In the extended description of the species, Roberts et al. (1990) provided a description of the species call, supplemented with a sound spectrogram. The call description was based on 19 analogue recordings from the lectotype and paralectotype (JDR tapes 66 and 67; JDR cassette No. 7), currently held at CENRM. One paralectotype (R94457) could not be located and has not been sighted in audits dating back to October 1998; the specimen is presumed lost.

Geocrinia vitellina Wardell-Johnson & Roberts, 1989

Wardell-Johnson, G. and Roberts, D. (1989) Endangered! Forest frogs. *Landscope* **5**(1): 17 [17].

Lectotype

R94467, 'intersection of Spearwood Creek and Denny road, 20.4 km ESE Witchcliffe, WA (34°04'S, 115°19'E)', G. Wardell-Johnson and D. Roberts, 15 November 1985.

Paralectotypes (12)

R86472–83, Spearwood Creek, 20.4 km ESE Witchcliffe, WA.

Remarks

This species, along with *G. alba*, was first presented as a new species by Wardell-Johnson and Roberts (1989) in the popular glossy-paged magazine *Landscope*. Although the publication did not provide a full description of the species, nor nomination of type material, the name was proposed with sufficient accompanying diagnostics, to qualify at the time as a valid description in zoology under the International Code of Zoological Nomenclature, then third edition (ICZN 1985); see account for *G. alba* above. As for *G. alba,* Roberts et al. (1990) presented an extended description including call descriptions in addition to identifying the syntype series and nominating a lectotype for the species. The call description was based on 15 recordings of which eight were from paralectotype specimens (R86472–79). Analogue recordings are currently held at CENRM.

Glauertia russelli Loveridge, 1933

Loveridge, A. (1933) A new genus and three new species of crinine frogs from Australia. *Occasional Papers of the Boston Society of Natural History* **8**: 89–94 [89].

Holotype

R2608, 'bank of a creek [Aurillia Creek] flowing into Gascoyne River near Landor Station, WA' [24°53'S, 116°59'E], L. Glauert, collection date unknown.

Paratypes (17)

R2609–25, Aurillia Creek, WA.

Current nomenclature

Uperoleia russelli, see Tyler et al. (1981a).

Remarks

The collection data for the holotype is not specified in specimen records; however, Glauert visited Landor Station between 8 April and 20 May 1929 for a collecting expedition during which is it likely the specimen was collected (Anonymous 1929a, b, c). Tyler et al. (1981a) stated the collection year for the holotype specimen (R2608) as '(1929?)'. Loveridge (1933) stated 'Twenty-four specimens with the same history as the type' under paratypes; however, he only provided a registration number for one specimen under measurements (MCZ 19424). Parker (1940) lists seven specimens examined, including two from the SUM which are listed as paratypes; however, no registration numbers are presented. Tyler et al. (1981a) presented

additional information on the holotype specimen and lists of 24 paratypes; however, the origins of the paratype list were not detailed and no specimens from SUM are listed. Tyler et al (1981a) listed 17 paratypes from WAM (R2609–25), six from MCZ (MCZ 19424–29) and one from SAMA (SAMA R9723) followed by 'all taken with the holotype'.

Kyarranus kundagungan Ingram & Corben, 1975

Ingram, G.J. and Corben, C.J. (1975) A new species of *Kyarranus* (Anura: Leptodactylidae) from Queensland, Australia. *Memoirs of the Queensland Museum* **17**(2): 335–359 [339].

Paratype

R45071, Mistake Mountains, 83 km SW Brisbane, Qld.

Current nomenclature

Philoria kundagungan, see Cogger et al. (1983) and Knowles et al. (2004).

Remarks

Holotype in the QM collection: QM J23944, 'Mistake Mountains (Lat. 27°53'S, Long. 152°21'E), about 800 metres above sea level, and 83 km southwest of Brisbane, SE. Queensland', C.J. Corben and A.K. Smyth, 3 January 1974. Single paratype gifted to WAM by authors, date unknown. Additional paratypes deposited in other collections: seven at QM (QM J23945, J22677–81, J23946), two at AMS (AMS R38193–94; Shea and Sadlier 1999), two at SAMA (SAMA R13921–22; Tyler 1976), one at NMV (NMV D33826) and one at QVM (QVM 1974/4/1) (Ingram and Corben 1975).

Pseudophryne brooksi Loveridge, 1933

Loveridge, A. (1933) Four new crinine frogs from Australia. *Occasional Papers of the Boston Society of Natural History* **8**: 55–60 [59].

Paratype

R4584*, Manjimup, nr Pemberton, WA [34°15'S, 116°09'E].

Current status

Junior synonym of *Pseudophryne guentheri,* see Parker (1940).

Remarks

Under paratypes, Loveridge (1933) listed registration numbers for five specimens in the MCZ collection (MCZ 13027–31) and stated four others were donated to the AMS, WAM and BMNH, all with the same collection details as the holotype. Of the four paratypes donated, two are held in the BMNH collection (BMNH 1927.8.30.3–4; Parker, 1940), one at AMS (AMS R10911; Shea and Sadlier 1999) and one at WAM. Holotype housed in the MCZ collection: MCZ 13025, from 'Manjimup, near Pemberton, West Australia', collected by W.S. Brooks, 7 February 1927. The WAM paratype has not been sighted in previous type specimen audits dating back to December 1998 or subsequent searches since and is presumed lost.

Pseudophryne douglasi Main, 1964

Main, A.R. (1964) A new species of *Pseudophryne* (Anura: Leptodactylidae) from north-western Australia. *Western Australian Naturalist* **9**(3): 66–72 [66].

Holotype

R21255, 'Kookhabinna Gorge [Barlee Range], WA (23°10'S, 115°58'E)', A.R. Main, 18 August 1961.

Paratypes (7)

R11530–34, Shothole Canyon, Northwest Cape [nr Learmonth], WA; R20253, Mount Herbert [nr Tambrey HS], WA; R21256, Kookhabinna Gorge [Barlee Range], WA.

Remarks

No paratypes were designated in the original description; however, Main referred to 13 specimens under specimens examined (presumably including the holotype), six males, four female and three juveniles from 'Mount Herbert', 'Kookhabinna Gorge, Weeana, Butler's Gorge' and 'Shothole Canyon (N.W. Cape)' and referenced multiple collecting events in the introduction. Under Article 72. (b) and Recommendation 73D of the then current, first edition of the International Code of Zoological Nomenclature (ICZN 1961; Article 72.4.1 and 72.4.5 of the current fourth edition of the Code (ICZN 1999), the 12 additional specimens (excluding the holotype) are considered paratypes.

At the time of the description, only eight specimens of *P. douglasi* were held in the WAM collection and would have been available to Main. Excluding the holotype, the remaining seven specimens match some of the collection data presented by Main. No specimens associated with the localities Weeana or Butlers Gorge or collected by J.H. Calaby and A. Kluge presented in the description could be located in the WAM collection; however, it is not known if these specimens were deposited at the WAM or were held in the UWA Zoology Department and their current whereabouts are unknown. The five additional paratypes that cannot be located are presumed to be lost. All type specimens are whole specimens stored in 70% ethanol solution with the exception of R11533 which is a dry skeleton.

Pseudophryne nichollsi Harrison, 1927

Harrison, L. (1927) Notes on some Western Australian frogs, with descriptions of two new species. *Records of the Australian Museum* **15**: 277–287 [284].

Paratypes

Unknown.

Current nomenclature

Metacrinia nichollsi, see Roberts and Maxson (1989) and Parker (1940).

Remarks

Harrison (1927) identified 34 individuals used in the description, 28 collected from 'Pemberton, in Karri country, 218 miles [351 km] south of Perth, 28 August 1926', WA [34°26'S, 116°03'E], and six from 'Deep River, Nornalup, on the south coast', WA [35°00'S, 116°38'E], by G.E. Nicholls 30 November 1925. In the description for the species under '*Types*' Harrison states 'Holotype female and allotype male in the Macleay Museum of the University of Sydney. Paratype material will be distributed to the Western Australian Museum, Perth, the Australian Museum, Sydney, the British Museum, and the American Museum of Natural History'. There are, however, no specimens in the collection matching the type information provided or any record of specimens being received by the WAM or any other institutions listed by Harrison, including MMUS, see account for *Crinia rosea* Harrison, 1927 above. The numerous changes to staff and collections at the MMUS throughout its history are likely to have attributed to the unknown whereabouts of type material in the collection, see account for *Crinia rosea* above.

Parker (1940) made no reference to any specimens matching the type specimen information provided by Harrison in a subsequent publication on Australian frogs. As for *Crinia rosea*, no specimens or records of any of Harrison's *P. nichollsi* type material being deposited at the MMUS (van der Valk 1984; Glenn Shea, personal communication, 2016), AMS (Shea and Sadlier 1999; Glenn Shea, personal communication, 2016), AMNH (David Dickey, personal communication, 2016), BMNH (Jeff Streicher, personal communication, 2016) or WAM could be located and all type material is presumed lost.

Ranidella bilingua Martin, Tyler & Davies, 1980

Martin, A.A., Tyler, M.J. and Davies, M. (1980) A new species of *Ranidella* (Anura: Leptodactylidae) from northwestern Australia. *Copeia* **1980**(1): 93–99 [94].

Holotype

R59775, 'from swamp on E side of Spillway Creek at Spillway Bridge, 11.5 km by road N of Lake Argyle Tourist Village, Kimberley Division, WA (16°01'47"S, 128°47'08"E)', M. Davies, A.A. Martin and M.J. Tyler, 20 February 1977.

Paratypes (11)

R59776–77, Dead Horse Spring, 1.5 km NE Lake Argyle Village, WA; R59778–86, Mitchell Plateau, WA.

Current nomenclature

Crinia bilingua, see Heyer et al. (1982).

Remarks

Martin et al. (1980) state 'There are 36 paratypes…'; however, only 35 specimens were listed. There are 11 paratypes held in the WAM collection and the remainder are held in other museum collections: ten at SAMA (SAMA R16833–42), four at KU (KU 177596–97, 177593–94), two at AMS (AMS R74817–18), two at NTM (NTM 5838–39), two at QM (QM J31537–38), two at NMV (NMV D50571–72) and two at BMNH (BMNH 1977.2089, 1977.2090). An original University of Adelaide Zoology tag accompanying the holotype states 'Spillway Swamp, 11.5 km NE of Lake Argyle, W.A.' as the collection locality. Martin et al. (1980) stated call recordings were collected from the type locality and other nearby localities and provided information on call characteristics including audio spectrograms; however, no information is provided on which calls are associated with which specific male specimen, if any, or the location of recordings. No recordings, analogue or digital, could be located in the WAM collection matching the information provided in the description; however, digital call recordings collected by A.A. Martin with the recording date of 19–20 February 1977 from 'Lake Argyle Village' are housed at NMV following the digitisation of historic analogue recordings belonging to A.A. Martin (Katie Date, personal communication, 2016). While the calls were not linked to specific specimens, based on the date of recording and locality, the recording may belong to a number of specimens including the holotype (R59775) from 11.5 km N Lake Argyle Tourist Village, one of two paratypes (R59776 or R59777) from 1.5 km NE Lake Argyle Village in the WAM collection or one of eight other paratypes held in BMNH, NTM, QM or SAMA.

Spicospina flammocaerulea Roberts, Horwitz, Wardell-Johnson, Maxson & Mahony, 1997

Roberts, J.D., Horwitz, P., Wardell-Johnson, G., Maxson, L.R. and Mahony M.J. (1997) Taxonomy, relationships and conservation of a new genus and species of myobatrachid frog from the high rainfall region of southwestern Australia. *Copeia* **1997**(2): 373–381 [374].

Holotype

R119457, 'Mountain Road, 30 km NE Walpole, WA' [34°46'S, 116°57'E], P. Horwitz, J.D. Roberts and G. Wardell-Johnson, 24 January 1994.

Paratypes (4)

R119458–60, Mountain Road, 30 km NE Walpole, WA; R126469, Boronia Road, 25 km NE Walpole, WA.

Remarks

Of the four paratypes in the collection of the WAM, R119460 is an alizarin-alcian stained skeleton specimen with skin stored in a glycol solution and R126469 specimen is a partial dry skeleton with skin stored in a 70% ethanol solution. The remainder of the type series are whole specimens stored in 70% ethanol. One additional paratype (R46671) is held in SAMA. Roberts et al. (1997) described the species call structure based on recordings of seven males (cuts 1, 3–8, JDR Cassette no. 69). The sound spectrogram and oscillogram illustrating call structure in the description was from JDR Cassette No. 69.5. All recordings are currently housed in CENRM and are in the process of being digitised. Liver sample of the holotype stored at the EBU.

Taudactylus diurnus Straughan & Lee, 1966

Straughan, I.R. and Lee, A.K. (1966) A new genus and species of leptodactylid frog from Queensland. *Proceedings of the Royal Society of Queensland* **77**(6): 63–66 [63].

Paratypes (6)

R26337–42, Green's Falls, Maiala NP, Mt Glorious, Qld.

Remarks

Holotype specimen in QM: J13398, 'Green's Falls, Maiala National Park, Mt Glorious, Queensland' [27°20'S, 152°46'E], I.R. Straughan, 12 May 1965. Straughan and Lee (1966) do not list any paratype registration numbers in the description, stating 'Paratypes, including males and females (collected at the same time and place as holotype) are deposited in the Queensland Museum, Australian Museum, Sydney and Western Australian Museum'. Only six specimens (three males, three females) of the 10 *T. diurnus* specimens held in the WAM collection match the collection data of the holotype presented in the description, R26337–41 we regard as paratypes, with the four other specimens not regarded as paratypes. In addition to the holotype, 13 paratypes are held in the QM (QM J13399–411; Covacevich 1971; Andrew Amey, personal communication, 2016) and a further six paratypes are held in the AM collection (AMS R24656–61; Shea and Sadlier 1999). In the AMS type list (Shea and Sadlier 1999), only three paratype specimens held in the WAM collection were listed; there are in fact six. We note that the species was last seen in 1979 and is presumed extinct (Conrad Hoskin, personal communication, 2016).

Uperoleia aspera Tyler, Davies & Martin, 1981

Tyler, M.J., Davies, M. and Martin, A.A. (1981) New and rediscovered species of frogs from the Derby-Broome area of Western Australia. *Records of the Western Australian Museum* **9**(2): 147–172 [159].

Holotype

R69648, '28 km S of Derby, Kimberley Division, WA (123°43'S, 17°30'E [in error, 17°30'S, 123°43'E])', M. Davies, A.A. Martin and M.J. Tyler, 14 February 1980.

Paratypes (10)

R69649, 28 km S of Derby, WA; R69650, 20–41 km S Derby, WA; R69651–52, 41 km S Derby, WA; R69653–54, Great Northern Hwy, 167 km E Broome, WA; R69655–58, Great Northern Hwy, 8 km NE Broome, WA.

Remarks

The latitude and longitude presented for the holotype by Tyler et al. (1981) is in error, the latitude and longitude coordinates have been switched and the correct coordinates associated with the type locality are 17°30'S, 123°43'E. Of the 19 paratypes designated by Tyler et al. (1981b), 10 are held in the WAM collection, the remainder are held in other collections: six at SAMA (SAMA R18093–97), one at AMS (AMS R95416), one at AMNH (AMNH 106556) and one at KU (KU 186040). The mating call for the species is described in the species description and supplemented with an audio spectrogram; however, no information is provided to indicate what specimens, if any, the calls are associated with. No recordings, analogue or digital, are held in the WAM collection; however, digitised copies of analogue calls recorded by A.A. Martin are held in the NMV collection, recorded 14 February 1980 from 22 km south of Derby. The recordings may belong to a number of paratypes held in the WAM collection in addition to specimens held in the BMNH and SAMA collections collected 20–41 km south of Derby; however, it is not clear which individual specimens the calls belong to based on the limited information associated with the recordings (Katie Date, personal communications, 2016).

Uperoleia borealis Tyler, Martin & Davies, 1981

Tyler, M.J., Davies, M. and Martin, A.A. (1981) Australian frogs of the leptodactylid genus *Uperoleia* Gray. *Australian Journal of Zoology Supplementary Series* **79**: 1–64 [30].

Holotype

R62474, 'Dead Horse Spring, 3.7 km north-east of Lake Argyle Tourist Village, Kimberley Division, WA (16°06'S, 128°45'E)', M. Davies, A.A. Martin and M.J. Tyler, 19 February 1977.

Paratypes (7)

R62475–79, R62480*, Dead Horse Spring, 3.7 km NE Lake Argyle Tourist Village, WA; R62481, Cave Springs, 30 km NE Kununurra, WA.

Remarks

One paratype specimen, R62480 was not located in February 2008 and has not been located in subsequent searches and type audits; accordingly, the specimen is considered lost. Of the 13 paratypes designated by Tyler et al. (1981a), five are held in SAMA and one in BMNH.

Uperoleia crassa Tyler, Martin & Davies, 1981

Tyler, M.J., Davies, M. and Martin, A.A. (1981) Australian frogs of the leptodactylid genus *Uperoleia* Gray. *Australian Journal of Zoology Supplementary Series* **79**: 1–64 [34].

Holotype

R59951, 'Amax Campsite, Mitchell Plateau, Kimberley Division, WA (14°15'S, 125°50'E)', M. Davies, A.A. Martin and M.J. Tyler, 28 January 1978.

Paratypes (23)

R43298–99, R43303–04, R43315–16, R59952–55, R59956–68, Mitchell Plateau, WA.

Remarks

Tyler et al. (1981a) designated 43 paratypes; however, the description states 'There are 42 paratypes', which is believed to be a typographical error and all 43 specimens are considered paratypes. There are 23 paratypes held in WAM and the remainder are in SAMA (17), KU (2) and BMNH (1). All WAM paratypes have University of Adelaide Zoology specimen tags attached with relevant species, type and collection data. Three additional specimens not listed in the description (R59969–71) also have University of Adelaide Zoology tags attached which state: '*Uperoleia crassa*' and 'paratype'; however, there is no mention of these specimens in the description.

Uperoleia glandulosa Davies, Mahony & Roberts, 1985

Davies, M., Mahony, M. and Roberts, J.D. (1985) A new species of *Uperoleia* (Anura: Leptodactylidae) from the Pilbara region, Western Australia. *Transactions of the Royal Society of South Australia* **109**(3): 103–108 [103].

Holotype

R89489, 'Petermarer Creek, Port Hedland-Broome road, WA (21°23'06"S, 118°48'21"E)', M. Mahony and J.D. Roberts, 10 January 1983.

Paratypes (4)

R22921, 5 km E Mundabullangana HS, WA; R89490–92, Petermarer Creek, Port Hedland-Broome Rd, WA.

Remarks

Of the seven paratypes designated by Davies et al. (1985), four are held in the WAM, two at SAMA (R27081–82) and a single specimen at AMS (AMS R114573). Call recordings described in the original description were from two frogs, recordings (JDR Tape 64, tracks 9 and 10), currently held at CENRM; however, it is not known to which individuals of the type series the calls are associated.

Uperoleia lithomoda Tyler, Davies & Martin, 1981

Tyler, M.J., Davies, M. and Martin, A.A. (1981) Australian frogs of the leptodactylid genus *Uperoleia* Gray. *Australian Journal of Zoology Supplementary Series* **79**: 1–64 [43].

Holotype

R61620, 'Spillway Bridge, 11.5 km north-east of Lake Argyle Tourist Village, Kimberley Division, WA (16°02'S, 128°47'E)', M. Davies, A.A. Martin and M.J. Tyler, 20 February 1977.

Paratypes (2)

R61621–22, 11.5 km NE Lake Argyle Tourist Village, WA.

Remarks

Of the 15 paratypes designated by Tyler et al. (1981a) only two are held by WAM and the remainder are housed in other collections: ten at SAMA (SAMA R17008–12, R17220, R17179–81, R17218), one at NTM (NTM R6936), one at BMNH (BMNH 1978.1207) and one at KU (KU 182219).

Uperoleia micra Doughty & Roberts, 2008

Doughty, P. and Roberts, J.D. (2008) A new species of *Uperoleia* (Anura: Myobatrachidae) from the northwest Kimberley, Western Australia. *Zootaxa* **1939**: 10–18 [12].

Holotype

R168043, 'near Bachsten Creek near southwest corner of the Prince Regent River Nature Reserve [now National Park], WA (15°59'29"S, 125°19'54"E)', J.D. Roberts, R. Barrett, P. Doughty and M. Barrett, 22 January 2007.

Paratypes (8)

R164897–98, Katers Is, WA; R166476, Walcott Inlet, WA; R167989, Prince Regent River NR [NP], WA; R168039–40, R168042, R168044, Bachsten Creek, Prince Regent River NR, WA.

Remarks

Of the eight paratypes held in WAM, one is a metamorphosing individual (R166476) and the remainder are adults. Four advertisement calls were recorded and used for the species call description, from R168042 (field recording JDR#2, track 50), R168043 (field recording JDR#3, track 3), R168044 (field recording PD/MB#1) and a fourth individual that was not captured. Digital call recordings of R168044 and the uncaptured specimen are held at the WAM. Digital recordings of R168042 and R168043 are currently housed at CENRM. Liver sample of the holotype and all eight paratypes stored in 100% ethanol solution at the WAM.

Uperoleia minima Tyler, Martin & Davies, 1981

Tyler, M.J., Davies, M. and Martin, A.A. (1981) Australian frogs of the leptodactylid genus *Uperoleia* Gray. *Australian Journal of Zoology Supplementary Series* **79**: 1–64 [49].

Holotype

R62482, 'Amax Crusher Site, 5 km south-west of the Mining Camp, Mitchell Plateau, Kimberley Division, WA (14°50'S, 125°50'E)', M. Davies, A.A. Martin and M.J. Tyler, 14 February 1979.

Paratypes (7)

R62483–89, Mitchell Plateau, WA.

Remarks

Of the 15 paratypes, seven are in WAM and the remainder are housed in other collections: six at SAMA (SAMA R17081, R17088–89, R17085–87), one at BMNH (BMNH 1979.4) and one at KU (KU 182200).

Uperoleia saxatilis Catullo, Doughty, Roberts & Keogh, 2011

Catullo, R.A., Doughty, P., Roberts, J.D. and Keogh, J.S. (2011) Multi-locus phylogeny and taxonomic revision of *Uperoleia* toadlets (Anura: Myobatrachidae) from the western arid zone of Australia, with a description of a new species. *Zootaxa* **2902**: 1–43 [23].

Holotype

R162877, 'Turee Creek, WA (23°20'37.6"S, 118°01'16.6"E)', P. Doughty, C. Stevenson and P.G. Kendrick, May 2006.

Paratypes (10)

R110883, 36.8 km SSE Pannawonica, WA; R135086, Hamersley Gorge, Karijini NP, WA; R135639, Pinga Creek crossing, WA; R140012, Millstream Chichester NP, WA; R145561, 80 km S Port Hedland, WA; R154550, Wheelarra Hill, WA; R154764, Brockman Ridge, WA; R156222, Cattle George, WA; R156614, Woodie Woodie Minesite, WA; R166206, 10 km S Nullagine, WA.

Remarks

Two advertisement calls by the holotype (R162877) were recorded and used in the analysis for the species description; the digital recording is held at the WAM. Liver sample of the holotype stored frozen (-75°C) at the WAM. Liver sample of all ten paratypes stored frozen (-75°C) at the WAM.

Uperoleia stridera Catullo, Doughty & Keogh, 2014

Catullo, R.A., Doughty, P. and Keogh, J.S. (2014) A new frog species (Myobatrachidae: *Uperoleia*) from the northern deserts region of Australia, with a redescription of *U. trachyderma*. *Zootaxa* **3753**(3): 251–262 [258].

Holotype

R164738, '13 km W of Fitzroy Crossing, WA (18°08'25.7"S, 125°29'32.9"E)', P. Doughty, P. Oliver and D. Moore, 15 January 2008.

Paratypes (3)

R164691, 35 km SE Fitzroy Crossing, WA; R164718, R164722, 75 km SE Fitzroy Crossing, WA.

Remarks

A further six paratypes are in NTM. Advertisement calls by the holotype (R164738; genetic code – Up0261) were recorded and described in the species description, supplemented with an oscillogram and spectrogram. The digital recording of the holotype is held at WAM (field recording PD#1). Digital recordings of two additional paratypes used in the call description, R164718 (field recording PD.Pond#2, recording#1) and R164722 (field recording PD.Pond#3, recording #1), are held at WAM. Liver sample of the holotype and all three paratypes stored in 100% ethanol solution at WAM.

Uperoleia talpa Tyler, Martin & Davies, 1981

Tyler, M.J., Davies, M. and Martin, A.A. (1981) Australian frogs of the leptodactylid genus *Uperoleia* Gray. *Australian Journal of Zoology Supplementary Series* **79**: 1–64 [52].

Holotype

R62472, '24 km south of Derby, WA (17°37'S, 123°36'E)', M. Davies, A.A. Martin and M.J. Tyler, 13 February 1979.

Paratype

R62473, 24–41 km S Derby, WA.

Remarks

Two paratypes were designated by Tyler et al. (1981a): one is in WAM and the other in SAMA (SAMA R17174). The holotype (R62472) is a whole specimen in a 70% ethanol solution and paratype R62473 is an alizarin stained skeleton stored in a glycol solution.

Uperoleia variegata Tyler, Martin & Davies, 1981

Tyler, M.J., Davies, M. and Martin, A.A. (1981). Australian frogs of the leptodactylid genus *Uperoleia* Gray. *Australian Journal of Zoology Supplementary Series* **79**: 1–64 [55].

Holotype

R62461, 'homestead garden at Gibb River Station, Kimberley Division, WA (16°26'S, 126°26'E)', A.K. Lee, 10 June 1965.

Paratypes (10)

R62462–71, Gibb River Stn, WA.

Current status

Junior synonym of *Uperoleia lithomoda,* see Davies et al. (1986) and Tyler et al. (1987).

Remarks

Of the 39 paratypes designated by Tyler et al. (1981a), 10 are held in the WAM collection, the remainder are held in other collections: 20 at SAMA (SAMA R17197–215, R17219), seven at KU (KU 181003–09) and two at BMNH (BMNH 1979.5, 1979.6). Davies et al. (1986) state '*U. variegata*... referred to the synonymy of *U. lithomoda* by Tyler et al. (in press)'; however, the synonymy was first made by Davies et al. (1986) as that publication antedates Tyler et al. (1987).

Family Pelodryadidae

Cyclorana longipes Tyler & Martin, 1977

Tyler, M.J. and Martin, A.A. (1977) Taxonomic studies of some Australian leptodactylid frogs of the genus *Cyclorana* Steindachner. *Records of the South Australian Museum* **17**(15): 261–276 [271].

Holotype

R43258, 'Mitchell Plateau, Kimberley Division, WA (140°52'S, 125°50'E [in error, 14°52'S, 125°50'E])', L.A. Smith and R.E. Johnstone, 5 February 1973.

Paratypes (43)

R14157, Broome, WA; R32349–51, Wyndham, WA; R42388, Mt Phire, WA; R43199–200, R43268–75, R43294–95, R43346, Mitchell Plateau, WA; R44735–59, Lake Argyle, WA.

Remarks

The latitude presented for the holotype by Tyler and Martin (1977) added an extra zero; the coordinates provided with the specimen when lodged with the WAM were 14°52'S, 125°50'E.

Cyclorana maini Tyler & Martin, 1977

Tyler, M.J. and Martin, A.A. (1977) Taxonomic studies of some Australian leptodactylid frogs of the genus *Cyclorana* Steindachner. *Records of the South Australian Museum* **17**: 261–276 [273].

Paratypes (84)

R1440, Laverton, WA; R1510–11, Booylgoo Stn, WA; R10216, R28634–35, R28638–48, R39193–94, Mundabullangana, WA; R10634, Roebourne, WA; R20546, Nannine, WA; R28486–508, Mt Edgar, WA; R28517, R28536, Jiggalong, WA; R28795, New Yamarna, WA; R28806–07, 44 km SE Leonora, WA; R28984–85, R28987, 8 km S Mundabullangana, WA; R29127–28, Roebourne Christchurch Grammar School, WA; R31444, presumably nr Exmouth, WA; R32373–80, R32382, Koordarrie, WA; R33188, R33212*, R34791, R34793, Woodstock, WA; R34206–07, Wittenoom, WA; R34208, S Wanning, WA; R36092, 40 km N Carnarvon, WA; R36094–96, nr Winning, WA; R36105–06, Barrabiddy Creek, WA; R36695, Mandidjarra, WA; R37248, Angel Is, WA; Dampier Archipelago, WA; R39147, Talawana, WA; R40355, Durba Hills, WA; R45665–67, Bamboo Creek, WA.

Remarks

Tyler and Martin (1977) state 'There are 95 paratypes' but they list 101 registration numbers, all as *C. maini*. As there is no distinction as to which registration numbers listed, if any, were to be excluded from paratype status, all specimens listed under 'paratypes' are considered paratypes here. Holotype in SAMA: R15191, 'Barrow Creek, NT' [21°25'S, 133°57'E], collected by D.F. Gartside and B. Low, 11 December 1971. Six additional paratypes held in the SAMA collection (SAMA 15192, 6311, 14715, R13038 A–D, R1711) and four in the NTM collection (NTM 2309–11 (now NTM R30034–35, 2316 (now NTM R30037), 3177 (now NTM R30079) (Horner 1999). One specimen, R33212, from Woodstock, WA, could not be located and is presumed lost.

Cyclorana occidentalis Anstis, Price, Roberts, Catalano, Hines, Doughty & Donnellan, 2016

Anstis, M., Price, L., Roberts, J.D., Catalano, S.R., Hines, H.B., Doughty, P. and Donnellan, S.C. (2016) Revision of the water-holding frogs, *Cyclorana platycephala* (Anura: Hylidae), from arid Australia, including a description of a new species. *Zootaxa,* 4126, 451–479 [469].

Holotype

R111826, '55 km E Newman, Pilbara, WA (23.4908°S, 120.3172°E [23°29'26"S, 120°19'01"E]), P. Doughty, 4 October 2005.

Paratypes (32)

R28551, R28553–54, R135042, Jigalong, WA; R28972, 33.6 km S New Mundiwindi, WA; R28977, 22.4 km N Leonora Laverton Road junction, WA; R48990, 12 km E Laverton, WA; R54386, Meekatharra, WA; R61331, 4 km S Mount Narryer HS, WA; R63113, 15 km SSW Nullagine, WA; R63834–35, Condegoon Pool, WA; R64971–72, 11.5 km N Erlistoun, WA; R103570–71, 20 km N Carnarvon, WA; R113403, 11 km S Pinjin HS, WA; R113405, 40 km N Mavis Rock, WA; R114053, 45 km SW Tangadee HS, WA; R119798, Barrabiddy Creek, WA; R119802–03, 9 km N Carey Downs HS, WA; R129994, R129998, nr Mt Joel, WA; R135899, 74 km WSW Kumarina Roadhouse, WA; R140796–97, between Kumarina Roadhouse and Yanneri Pool, WA; R154928–29, Yalgoo, WA; R165306, 51.3 km S Leinster, WA; R177495–96 [in error, R174495–96], Mount Augustus NP, WA.

Remarks

No paratypes were designated in the species description; however, the 40 specimens of the species examined listed in the appendix are all considered paratypes under Article 72.4.1 and 72.4.5 of the International Code of Zoological Nomenclature (ICZN 1999). Five additional paratypes held at the AMS (AMS R182001–05) and three at SAMA (SAMA R168162, R168164–65). The holotype registration is presented with two different localities; however, both refer to the same location, '55 km E Newman, Pilbara' under the holotype listing and '11 km N Red Hill' in the appendix of specimens examined. Two WAM paratype registration numbers are presented in error, R177495–96. There are currently no specimens associated with those registration numbers and the correct registrations with specimens matching the locality data presented are R174495–96. Liver sample of the holotype (R111826) stored frozen (-75°C) at the WAM. Liver samples of 14 paratypes stored frozen (-75°C; R113403, R113405, R114053, R119798, R119802–03, R129994, R135042, R135899, R140796–97, R154928–29, R165306) and two in ethanol (R177495–96) at the WAM. Heart samples for seven paratypes (R113403, R113405, R114053, R119798, R119802–03, R129994) stored frozen (-75°C) at the WAM.

Cyclorana vagitus Tyler, Davies & Martin, 1981

Tyler, M.J., Davies, M. and Martin, A.A. (1981) New and rediscovered species of frogs from the Derby-Broome area of Western Australia. *Records of the Western Australian Museum* **9**(2): 147–172 [148].

Holotype

R71037, 'by the roadside at the junction of the Great Northern Highway and the road to Derby, 41 km S of Derby, Kimberley Division, WA (17°44'S, 124°38'E [17°38'S, 123°44'E])', A.H. Cross, M. Davies, AA. Martin and M.J. Tyler, 14 February 1980.

Paratypes (13)

R27251, Duncan Hwy, 17 km N Lake Argyle, WA; R58836–37, R71039, Parry Creek Rd, Kununurra, WA; R71029, Camballin, WA; R71030–36, 41 km S Derby, WA; R71038, 29 km S Northern Hwy and Duncan Hwy junction, WA.

Remarks

Tyler et al. (1981b) state 'There are 26 paratypes…'; however, only 21 specimens were listed. Of the 21 paratypes, 13 are held in the WAM collection and the remainder are held in other museum collections: four at SAMA (SAMA R18008–10, R16535), one at AMS (AMS R95415), one at KU (KU 186039), one at BMNH (1880.4) and one at AMNH (AMNH 106555).

The spelling of the name has been variously reported as '*vagitus*' or '*vagita*' (for examples see Tyler and Doughty 2009; Tyler and Knight 2011; Anstis 2013). The original etymology indicates *vagitus* is a noun in apposition or could be so treated, and so does not follow the gender of the generic name, and will always remain '*vagitus*' (Meagher 2015).

Hyla coplandi Tyler, 1968

Tyler, M.J. (1968) A taxonomic study of hylid frogs of the *Hyla lesueuri* complex occurring in north-western Australia. *Records of the South Australian Museum* **15**: 711–727 [716].

Holotype

R13722G, 'Inverway Station, NT' [17°51'S, 129°38'E], K.G. Buller, 8 August 1960.

Paratypes (7)

R13722E*, F*, Inverway Stn, NT; R13724A–D, R13724I, Wave Hill, NT.

Current nomenclature

Litoria coplandi, see Tyler (1971).

Remarks

Two specimens, R13722E and R13722F could not be located and are presumed lost. A single specimen with a damaged registration tag showing only R13722 was located; however, it is unknown which of the five remaining registrations suffixed with A–F this specimen is associated with. A second tag label attached to the specimen with collection and locality information states paratype, though no additional information is available to distinguish which A–F suffix it is associated with. As all specimens registered as R13722 are from the same (type) locality the specimen with the unknown A–F suffix is retained as a paratype. An additional paratype is held in the SAMA collection, SAMA R9103 (formerly WAM R13722D). The three specimens associated with the R13722A–C are listed as specimens of *H. coplandi* examined by Tyler; however, they are not listed as paratypes and so we do not regard them as such.

Hyla latopalmata watjulumensis Copland, 1957

Copland, S.J. (1957) Presidential address. Australian tree frogs of the genus *Hyla*. *Proceedings of the Linnean Society of New South Wales* **82**: 9–108 [96].

Syntypes (36)

R8733–34, 'Thompson's Spring, Argyle Stn, WA' [16°01'S, 128°56'E], collected by C.F.H. Jenkins, 23 May 1944; R10491 [in error, 10491*], 10499 (now R138068*), 10501 (now R138069*), 'Napier Broome Bay, WA' [14°02'S, 126°36'E], collected by G.F. Hill, 26 August 1910; R11195–99, R11633–35, R11638, R11896–907, R11932–39, R29763 (formerly part of R11897), R175032 (formerly part of R11896), 'Watjulum [Wotjulum] Mission, WA' [16°11'S, 123°37'E], all collected by K.G. Buller and A.M. Douglas, collection date not known (but other specimens in the series were collected in 1954).

Current nomenclature

Litoria watjulumensis, see Tyler (1968) for species status and Tyler (1971) for generic placement, see Shea and Sadlier (1999) and Tyler and Doughty (2009) for spelling of species epithet.

Remarks

Copland listed 36 specimens with museum registration numbers and locality data under 'specimens examined and locality records' in the original description; however, no type specimens were designated or presented. In the discussion section of the species description, however, Copland stated 'The type locality Watjulum Mission...'. Tyler (1968) subsequently identified the 29 specimens from the type locality of 'Watjulum Mission' as syntypes and excluded the remaining seven specimens as not from the same locality presented by Copland from WAM (R10491, R1049 and R10501 from Napier Broome Bay and R87333–34 from Thompson's Spring) in addition to specimens from other institutions (AMS R6011 from Napier Broome Bay and MCZ 18000 from Kimberley division). Of the 29 registration numbers presented by Tyler (1968), four syntypes were identified as other species, one as '*Hyla peroni*' (=*Litoria rothii*) (R11195) and three as 'representatives of a new species described in the present paper' (=*Hyla* [*Litoria*] *coplandi*) (R11197, R11638 and R11939). Tyler also identified two specimens bearing the registration number R11897, one of which was subsequently re-registered as R29763. This specimen was then excluded as a syntype despite there being no indication as to whether the specimen was or was not known to Copland at the time of the description. A further seven specimens listed by Copland considered to be syntypes were not located by Tyler (1968): R11196, R11634–35, R11900, R11904–05, R11934. Of the 29 syntypes recognised by Tyler (1968), only 22 syntypes were presented in the WAM Annual Report 1968–1969 (Anonymous 1969) (R11195, R11197–99, R11633, R11638, R11896–99, R11901–03, R11906–07, R11932–33, and R11935–39). Cogger et al. (1983) listed 25 syntype specimens, excluding four of the 29 syntypes presented by Tyler (1968) (R11195, R11197, R11638 and R11939) which were identified as different species (see above). Cogger (1979) and Shea and Sadlier (1999) list the single AMS specimen (R6011) listed by Copland as a syntype, a specimen excluded from the list of syntypes presented by Tyler (1968) for not being from the type locality. Some specimens examined by Copland (1957) were pre-1912 specimens and not formally registered into the current post-1912 registration system with an 'R' prefix. Of the 36 specimens listed by Copland (1957), three registration numbers pre-date the 1912 herpetological register, 'R.10491, 10499, 10501, W.M.', of which one (R.10491) is erroneously presented with an 'R' prefix. These pre-1912 registration numbers are listed in the 'Zoological Register 1907' as 'frog' and are part of a series (10491–10502) of frogs collected from Napier Broome Bay, entry dated 'August 29th 1910' (accession date). Two of these specimens, 10499 and 10501 were re-registered as R138068 and R138069 respectively on 8 July 1999. There is no indication which pre-1912 registration number corresponds with the current registration numbers. There is no record to indicate if the third pre-1912 registration number (10491, erroneously presented as R.10491) was ever identified or re-registered.

As Copland (1957) did not designate any type material, all specimens examined are considered syntypes in accordance with Articles 72.1.1, 72.4.1 and Article 73.2 of the International Code for Zoological

Nomenclature (ICZN 1999). The specimen re-registered by Tyler to R29763 (formerly R11897) is also considered a syntype here and is maintained in the type collection with other syntypes. There are two specimens of *L. watjulumensis* associated with the registration number R11896. To remove duplicate use of the registration R11896 for two specimens, the smaller specimen of the two has been reregistered as R175032. As it is not clear if Copland was aware of the multiple specimens associated with some registrations (R11896 and R11897) and if all specimens were examined, we maintain all four specimens (R11896, R11897, R29763, R175032) as syntypes.

Of the 36 WAM specimens considered to be syntypes, three are specimens of *Litoria coplandi* (R11197, R11638, R11939), two *Litoria meiriana* (R8733–34) and one *Litoria rothii* (R11195). Two specimens, R138068–69, for which Copland (1957) originally presented pre-1912 registration numbers for (10499 and 10501) could not be located and are considered lost. The third pre-1912 registration number presented by Copland (1957) (10491, erroneously presented as R.10491) could not be located and no evidence indicating the specimen was re-registered into the current herpetological catalogue could be located, the specimen's status is unknown and is considered lost.

Tyler (1968) also attempted to emend the specific epithet to *wotjulumensis* in reference to the type locality Wotjulum Mission, presented as 'Watjulum' in error by Copland; however, the amendment was unjustified as Copland throughout his description used the spelling 'Watjulum'. Hence, there is no evidence within the original description that Copland's use was incorrect and the specific epithet '*watjulumensis*' as presented by Copland (1957) is maintained here. As 'Watjulum' Mission is erroneous, we suggest the pronunciation remain as '*wotjulumensis*' in reference to the actual name of the mission.

Hyla moorei Copland, 1957

Copland, S.J. (1957) Presidential Address. Australian tree frogs of the genus *Hyla*. *Proceedings of the Linnean Society of New South Wales* **82**: 9–108 [83].

Lectotype

R5981, 'Pemberton, WA' [34°27'S, 116°02'E], W. Dean, collection date unknown (probably 1930s). Designation by Cogger et al. (1983).

Paralectotypes (38)

R119, Subiaco, WA; R301*, R302, Denmark, WA; R529–30, East Perth, WA; R627 [in error, R827*], Perth, WA; R1152–53, R2749, Tambellup, WA; R1178, Midland Junction, WA; R1210–13, Lake Yanchep, WA; R2025–27, R6268–76, Rottnest Is, WA; R3739, Mt Lawley, WA; R3800, Elleker, WA; R4585, Karridale, WA; R4664, Lake Clifton, WA; R5980, R8539–40, R175031 (formerly part of R5981), R176080 (formerly part of R5980), Pemberton, WA; R8404, Bridgetown, WA; R8462, Gin Gin, WA; R9459 (in error, now R176078), no locality data.

Current nomenclature

Litoria moorei, see Tyler (1971).

Remarks

A list of specimens examined was provided by Copland (pp. 83–84); however, there is no reference to designation of type specimens and all specimens examined are regarded as syntypes in accordance with Articles 72.1.1, 72.4.1 and Article 73.2 of the International Code for Zoological Nomenclature (ICZN 1999). Copland did not designate any types; however, stated 'Description of R5981 in Western Australian Museum'. The specimen R5981 was incorrectly listed as the holotype in the WAM 1962–1963 Annual Report type list (Anonymous 1963) and subsequently designated as lectotype (through Storr's inference of holotype) by Cogger et al. (1983). There are two specimens associated with the registration number R5981; however, the specimen listed above as the lectotype is consistent with the morphology and meristics of the specimen described by Copland (1957). There is no mention of two specimens by Copland (1957) or Cogger et al. (1983), so it is likely the second specimen was unknown by both sets of authors and possibly not examined. To resolve the status of these specimens, the lectotype specimen retains the original registration number of R5981, while the smaller specimen that was possibly unsighted by previous workers has been reregistered as R175031. There are also two specimens associated with the registration number R5980 of which the smaller of the two has been re-registered as R176080. Due to the uncertainty of which of the specimens with duplicate registrations were examined by Copland or previous workers, both re-registered specimens are also maintained as paralectotypes. The registration number R9459 is associated with two specimens, one *L. moorei* and one snake identified as *Pseudonaja affinis* from Guildford, WA. Examination of the original entry in the specimen register reveals the correct specimen associated with this registration number is the *P. affinis* which is also annotated with 'not kept' in the same hand as the accession entry. No additional information relating to the *L. moorei* specimen could be located; however, it is listed by Copland with 'no data' under specimens examined and locality records. To remove the erroneous duplicate use of the registration, the *L. moorei* specimen has been reregistered as R176078. One of the parelectotypes (R4585) is a specimen of *Litoria adelaidensis.*

Two specimens could not be located: R301 and R627. Of the two specimens, R301 has not been sighted in previous type audits since 1998 or subsequent searches and is presumed lost. The specimen associated with registration number R627 is *Ctenotus labillardieri*; it is possible that a typographical error occurred in the description and another specimen was intended to be listed. A specimen of *L. moorei* registered as R827 from East Perth was possibly available to Copland at the time of his description; however, registration data mentions this specimen had six legs, a fact not mentioned by Copland. Registration entries indicate the specimen was disposed of, date unknown. Fifty-eight additional paralectotypes held at AMS: AMS R2347–57; R4953–54; R5297–300; R7476; R7531; R7576–77; R7579–83; R7696; R7698–99; R7703; R7743–45; R10463; R10953; R11537; R131735–39 (formerly 7132, 7144, 7156–57, 7187); R131740–52 (formerly part of R2357); R131753–56 (formerly part of R10953)) (Shea and Sadlier, 1999).

Hyla spaldingi Hosmer, 1964

Hosmer, W. (1964) A new frog of the genus *Hyla* from Northern Territory, Australia. *American Museum Novitiates* **2182**: 1–7 [2].

Holotype

R23886 (formerly AMNH 67835), 'Elizabeth River, 50 miles [80 km, in error] south of Darwin, NT' [12°34'S, 131°00'E], W. Hosmer, 23 September 1960.

Current status

Junior synonym of *Litoria watjulumensis*, *fide* Tyler (1968).

Remarks

The holotype was formerly held in the AMNH (Anonymous 1965; Hosmer 1964) and gifted to WAM prior to 1965, and accessioned 27 January 1965. All paratypes remain in the collection of the AMNH (AMNH 67836–38, 65423–28). The type locality of Elizabeth River does not match the distance from Darwin presented by Hosmer and is likely erroneous, the mouth of Elizabeth River is located approximately 14 km ESE of Darwin and extends south-east and south for only approximately 28 km.

Litoria aurifera Anstis, Tyler, Roberts, Price & Doughty, 2010

Anstis, M., Tyler, M.J., Roberts, J.D., Price, L.C. and Doughty, P. (2010) A new species of *Litoria* (Anura: Hylidae) with a highly distinctive tadpole from the north-western Kimberley region of Western Australia. *Zootaxa* **2550**: 39–57 [41].

Holotype

R169913, 'creek near Bachsten Creek, Prince Regent River Nature Reserve [now National Park], WA (15°59'18.2"S, 125°19'38.1"E)', J.D. Roberts and P. Doughty, 23 January 2007.

Paratypes (22)

R168004, R168006, R168008–10, R168013–14, R168016–18, R168059, R168062, R168095, R168114, R168116, R168118, R168129, R168134, R168182–85, Bachsten Creek, Prince Regent River NR [NP], WA.

Remarks

The holotype was collected as a tadpole and raised to adult by M. Anstis before the species description. Paratype specimens include field-collected adults and two adults reared from tadpoles. Two additional paratypes are held in the SAMA collection (SAMA R63001–02). Although not mentioned in the species description, the call description is based on recordings from five male paratype specimens: R168006 (no field recording number), R168013 (field recording JDR#1, track 33), R168014 (field recording JDR#2, track 41), R168016 (field recording PD#1), R168017 (field recording JDR#5, track 43). Two digital recordings (R168006 and R168016) are held in the WAM, the remaining three paratype calls (R168013, R168014 and R168017) are also digital and currently housed in the CENRM. Liver sample of all 22 paratypes stored in 100% ethanol solution at the WAM.

Litoria axillaris Doughty, 2011

Doughty, P. (2011) An emerging frog diversity hotspot in the northwest Kimberley of Western Australia: another new frog species from the high rainfall zone. *Records of the Western Australian Museum* **26**: 209–216 [211].

Holotype

R171472, 'Prince Regent River, Kimberley region, WA (15°17'37"S, 125°29'46"E)', P. Doughty and M. Pepper, 19 January 2010.

Paratypes (3)

R169971, 9.3 km ENE King's Cascade, Prince Regent River; R171471, R171473, Prince Regent River, WA.

Remarks

The species call was described and supplemented in the species description with a spectrogram. Though not mentioned by Doughty (2011) the calls used for the description were from the holotype (R171472) and one paratype (R171473); the oscillogram is of the holotype call. Digital recordings of calls are deposited at the WAM. Liver sample of the holotype stored in 100% ethanol solution at the WAM. Liver samples of three paratypes stored in 100% ethanol solution (R171471, R171473) and frozen (-75°C; R169971) at the WAM.

Litoria cavernicola Tyler & Davies, 1979

Tyler, M.J. and Davies, M. (1979) A new species of cave-dwelling, hylid frog from Mitchell Plateau, Western Australia. *Transactions of the Royal Society of South Australia*, **103**:149–153 [149].

Holotype

R43328, '3 km west of Surveyors Pool, Mitchell Plateau, Kimberley Division, WA' [14°40'S, 125°44'E], L.A. Smith and R.E. Johnstone, 17 February 1973.

Paratypes (14)

R43329–30, 3 km W Surveyors Pool, Mitchell Plateau, WA; R60680, R60681*, R60682–84, E Mitchell Falls, WA; R61624–30, Mitchell Plateau, WA.

Remarks

One paratype (R60681) was not located during a type audit undertaken in 2008 and was not located in subsequent searches and is presumed lost.

Litoria splendida Tyler, Davies & Martin, 1977

Tyler, M.J., Davies, M. and Martin, A.A. (1977) A new species of large, green tree frog from northern Western Australia. *Transactions of the Royal Society of South Australia* **101**: 133–138 [133].

Holotype

R56840, 'Lake Argyle Tourist Village, Kimberley Division, WA' [16°07'S, 128°44'E], joint University of Adelaide and University of Melbourne field party [Melu et. al.], 22 February 1977.

Paratypes (6)

R26818, Old Napier Downs Cave, Napier Downs, WA; R44601–02, Lake Argyle, WA; R47231, Prince Regent River NP, WA; R56779, Kimbolton Spring, Kimbolton Stn, WA; R56780, Drysdale River NP, WA.

Litoria staccato Doughty & Anstis, 2007

Doughty, P. and Anstis, M. (2007) A new species of rock-dwelling hylid frog (Anura: Hylidae) from the eastern Kimberley region of Western Australia. *Records of the Western Australian Museum* **23**: 241–257 [243].

Holotype

R162611, 'The Grotto, 30 km south of Wyndham, WA (15°43'31.44"S, 128°16'46.31"E)', P. Doughty and C. Mills, 30 January 2006.

Paratypes (11)

R162512–14, R162537–38, R162612–16, R162620, Parry's Lagoon NR, 30 km south of Wyndham, WA.

Remarks

In the description there is a section labelled 'paratypes' (reported here), as well as a section labelled 'Embryos and Tadpoles' (listing 12 such specimens: R162946–57). We do not regard the latter as part of the type series. The calls of the holotype male (R162611) and one paratype (R162612) were recorded and analysed as part of the species description. Digital recordings of calls are held at the WAM. Liver sample of the holotype stored in 100% ethanol solution at the WAM. Liver sample of all 11 paratypes stored in 100% ethanol solution at the WAM.

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Further Mollusca from the late Eocene Pallinup Formation, Eucla Basin, Western Australia

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ABSTRACT – The molluscan fauna of the late Eocene Pallinup Formation from the southern coast of Western Australia consists of 30 species of bivalves, 125 gastropods, 1 scaphopod and 1 cephalopod. Of the gastropods, 29 are newly described, 13 have been previously described from the formation, 32 have been previously described from other localities and are here newly recorded from the formation and the rest are recorded in open nomenclature. The majority of the gastropods are carnivores that preyed on or were associated with sponges, cnidarians and tunicates. *Tenagodus occlusus* Tenison Woods is a very common gastropod, often found preserved within silicious sponges. The composition of the fauna shows that the Eucla Basin in the late Eocene was within the Southern Australian Province (70% of the genera present characteristic of the Province). The following are newly described: *Clavocerithium kendricki, Pseudovertagus? longbottomi, Mastoniaeforis pagodiformis, Inella moniliferata, Inella dauciformis, Costatophora? pulcherrima, Seila stenopyrgisca, Cerithiopsis pustuloclathrata, Ataxocerithium otopleuroides, Ataxocerithium venustulum, Ataxocerithium multicostulatum, Ataxocerithium biaulax, Trituba (Granulotriforis) umboseriata, Cerithiella limula, Tasmeuthria? arenicola, Dermomurex silicatus, Attiliosa arenaria, Eratoidea fusoides, Cryptospira hordeastra, Ovaginella mumiformis, Ovaginella arenula, Lyria craticulata, Conomitra strombodiformis, Belloliva canaliculata, Cordieria fuscoamnica, Cordieria torquata, Conorbis notialis, Neoguraleus filiferus, Comitas silicicola. Seraphs* is recorded for the first time from the Australian Tertiary.

KEYWORDS: Gastropoda, Scaphopoda, Cephalopoda, taxonomy, new species, siliceous fossils, Southern Australian Province, biogeography, paleoecology

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INTRODUCTION

Late Eocene molluscan faunas in Western Australia have been described from an unnamed sandstone near Kalbarri (Darragh and Kendrick 2008) and from the Merlinleigh Sandstone (Darragh and Kendrick 2010), both in the Carnarvon Basin, as well from the Pallinup Formation, Eucla Basin (formerly Bremer Basin) on the southern coast (Darragh and Kendrick 1980, 2000). In the latter case only the bivalves and 23 of the gastropods were described. This third paper concluding the work on the molluscan fauna of the Pallinup Formation describes and records the remaining gastropods, a scaphopod and a cephalopod.

The majority of the specimens dealt with in this paper, as in the two earlier papers, are siliceous replacements of carbonate shells, but a few are external moulds from which latex casts were made for study. Details of the preservation of the material and the localities from which specimens were collected have been given in the two previous papers and need not be repeated. Most of the material dealt with here has come from the locality beside the Thompson Road at North Walpole with a few specimens from Lucky Bay, east of Esperance, and from Ocumup no 1 deep well, near Bremer Bay. The specimens from the Thompson Road were collected by sieving the fossiliferous matrix, so the relative abundance of the specimens of each taxon is probably representative of the occurrence of the taxon at that locality. Since the two previous papers on the molluscs were published, there has been some revision of the stratigraphy and basin nomenclature of the area by Clarke et al. (2003). The Pallinup Siltstone was redefined as the Pallinup Formation and the term Bremer Basin was abandoned for the Eocene succession in favour of the Eucla Basin for the Eocene sediments that extend from west of Albany into South Australia.

Because the environment of the Pallinup Formation was one unusually rich in sponges (Gammon et al. 2000b), many of the molluscan taxa were probably spongivores or were associated with sponges in some way and represent genera and species hitherto not recorded either from the Australian Eocene or the Australian Tertiary in general. As a result generic assignments for many of the species are tentative, especially as preservation of critical details may be poor. A number of taxa are known from only very few specimens, often poorly preserved.

A complete list of the molluscan taxa recorded, including those in the two previous papers (Darragh and Kendrick 1980, 2000), is given in Table 1, which also records the occurrences of the species at other localities in the Australian Tertiary.

OTHER FAUNAL ELEMENTS

As well as molluscs, sponges, cnidarians, echinoderms, brachiopods, bryozoans, serpulids and other annelids, fish otoliths also occur in the formation but, with the exception of the sponges, these groups have not been studied. The sponge fauna has only been partly recorded. Pisera (2004) stated that in the Pallinup Formation at least 20 species of sponges representing the families Theonellidae (dominating), Phymatellidae, Phymaraphinidae, Pleromidae and Corallistidae and rhizomorine lithistids await description, and these 20 species were listed by Gammon et al. (2000, Table 1). Pisera and Bitner (2007) described a pachastrellid demosponge from the formation and Łukowiak (2015) described and illustrated over 43 taxa of sponges based on loose siliceous spicules from the Pallinup Formation including its Princess Royal Member and from the Blanche Point Formation of South Australia. Pickett (1982) described the calcareous demosponge *Vaceletia progenitor*, the only sponge as yet recorded from the North Walpole site. The specimens of *V. progenitor* are silicified, and Pickett reported that many lithistid sponges at the locality are also silicified to the extent that details of spiculation are obscured.

CORRELATION AND AGE

The Pallinup Formation was dated as late Eocene, Priabonian, by McGowran (2009), and is coeval with the Blanche Point Formation of South Australia and the Browns Creek Formation of Victoria.

Comparison and correlation with other Australian Eocene faunas using molluscs is hampered by factors that include geographical isolation from other localities of possibly similar age and, more importantly, facies differences. The depositional environment of the Pallinup Formation was particularly rich in sponges, which seems to have been unique, at least as far as the known outcrops of Eocene sediments in southern Australia is concerned. Nothing quite like this environment has been discovered in the Eocene formations of eastern Australia, although sponge spicules occur in the Blanche Point Formation (Łukowiak 2015). Nevertheless, similarities between the faunas of the east and west of the continent do exist and provide useful evidence for correlation (see Table 1).

Of the 30 bivalves recorded from the Pallinup Formation, 8 or 27% of the species are endemic and so of no value in correlation. Of these only one species, *Plicatula emaciata*, is represented by a large number of specimens. The other taxa are represented by only one to four specimens. Seven species (23% of the bivalve fauna) are closely related or identical to species occurring in the unnamed sandstone at Kalbarri (Darragh and Kendrick, 2008), whereas only one species, *Spondylus* cf. *S. gaderopoides* McCoy, 1876, occurs in the Merlinleigh Sandstone (Darragh and Kendrick, 2010). The differences in the faunas probably result from facies rather than stratigraphical differences. In comparing the bivalve fauna of the Pallinup Formation with those of the late Eocene faunas of eastern Australia, 67% of the bivalves are in common with those of the Blanche Point Formation of the St Vincent Basin, 33% are in common with those of the lower part of the Browns Creek Formation and 46% with those of the upper part of the Browns Creek Formation.

Of the 125 gastropods of the Pallinup Formation, 87 species (71% of the fauna) are endemic. Of the remainder, 31 (24%) also occur in the Blanche Point Formation, 32 (26%) in the lower Browns Creek Formation and 25 (20%) in the upper. With respect to the overall fauna, 32% of species occur in the Blanche Point Formation, 28% in the lower Browns Creek Formation and 26% in the upper. Allowing for the unique nature of the environment of the Pallinup Formation, the foregoing occurrences suggest a strong correlation with both the Blanche Point and Browns Creek formations. The lower percentages of the Browns Creek occurrences might be explained by the greater distance of Browns Creek, Victoria, from the Walpole area compared with that of Blanche Point, Aldinga, in South Australia.

PALEOECOLOGY

The Pallinup Formation is a heterogeneous unit of spiculite, spongolite, terrigenous sandstone and mudstone that outcrops along the southern coast of Western Australia from Northcliffe in the west to Mount Arid in the east. Sponges increasingly dominate the fossil fauna stratigraphically upward in the formation (Gammon et al. 2000b). Deposition is considered to have taken place under tropical to warm temperate conditions in shallow water embayments in a sheltered environment owing to the sheltering effects of shoals and islands. This protected environment mitigated the influence of storms and reproduced the relatively calm conditions that modern day deep water lithistid and hexactinellid sponges inhabit (Gammon et al. 2000a, b; Gammon and James 2001, 2003).

TABLE 1 Stratigraphic ranges (Middle Eocene to Middle Miocene) of selected bivalves and gastropods from Southern Australia. Sources: Ludbrook, 1961, 1965; Darragh and Kendrick, 1980; Darragh, 1985; Darragh and Kendrick, 2000; this paper; WAM and NMV collections. A = Carnarvon Basin, B = Eucla Basin, C = St Vincent Basin, D = Murray Basin, E = Otway Basin, F = Port Phillip Basin, G = Bass Basin. 1 = Unnamed formation, 2 = Werillup Formation, 3 = Pallinup Siltstone, 4 = Tortachilla Limestone, 5 = Blanche Point Formation, 6 = Morgan Limestone (Cadell Marl Member), 7 = lower Browns Creek Formation, 8 = upper Browns Creek Formation, 9 = lower Glen Aire Formation, 10 = Gellibrand Formation, 11 = Muddy Creek Formation, 12 = Jan Juc Formation, 13 = Fyansford Formation, 14 = Freestone Cove Sandstone.

		A	B		C		D	E					F		G
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Bivalves														
1.	*Nucula tatei* Finlay			x		x		x	x						
2.	*Nuculana* (*Saccella*) *chapmani* Finlay	x		x		x		x	x						
3.	*Sarepta planiuscula* (Tate)			x		x				x					
4.	*Arca pseudonavicularis* Tate			x		x			x						
5.	*Barbatia* (*B.*) *limatella* Tate		x	x		x			x						
6.	*Barbatia* (*Acar*) *gunsoni* Darragh and Kendrick		?	x		x									
7.	*Notogrammatodon cainozoicus* (Tate)		x	x		x	x	x	x	x	x	x			x
8.	*Arcopsis dissimilis* (Tate)			x		x		x							
9.	*Limopsis* (*L.*) *chapmani* Singleton	x	x	x		x		x	x	x					
10.	*Limopsis* (*L.*) *multiradiata* Tate			x		x		x	x						
11.	*Tucetona lenticularis* (Tate)	x	x	x		x		x	x	x					
12.	*Limarca angustifrons* Tate			x		x				x					
13.	*Septifer* (*S.*) *subfenestratus* Basedow			x		x									
14.	*Vulsella laevigata* Tate	cf		x	x										
15.	*Plicatula* (*P.*) *emaciata* Darragh & Kendrick			x											
16.	*Anomia* (*A.*) *cymbula* Tate			cf		x									
17.	*Spondylus gaderopoides* McCoy			cf	x				x				x		
18.	*Dimya sigillata* Tate			x		x			x	x					
19.	*Limea* (*Gemellima*?) sp.			x											
20.	Limid, gen. & sp. undetermined			x											
21.	*Epicodakia* sp.			x											
22.	*Venericardia* (*Rotundicardia*) *latissima* (Tate)	cf		x		x		x	x						
23.	*Cyclocardia* (*Vimentum*?) sp.			x											
24.	*Salaputium communis* (Tate)			x		x		x	x	x					
25.	*Hedecardium moniletectum* (Tate)			x		x									
26.	*Glossus* (*Miocardiopsis*) sp.			x											
27.	*Dosina multilamellata* (Tate)	x		x		x			x				x		x
28.	*Corbula* (*Caryocorbula*) *pixidata* Tate	x		x		x		x	x	x					
29.	*Verticordia* sp. A			x											
30.	*Verticordia* sp. B			x											
	Total bivalves	**7**	**5**	**30**	**2**	**20**	**1**	**10**	**14**	**8**	**1**	**1**	**2**	**0**	**2**
	Gastropods														
31.	*Nacella*? *jutsoni* (Chapman and Crespin)			x											
32.	*Emarginula*? sp.			x											

		A	B		C		D	E					F		G
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
33.	*Liotina lamellosa* (Tenison Woods)		x	x				x		x		x	x		x
34.	*Angaria* (*Pseudoninella*)? sp.		x	x											
35.	*Homalopoma* (*H.*) *limnaios* Darragh & Kendrick			x											
36.	*Eutinochilus otwayensis* (Pritchard)		x	x		x			x	x					
37.	*Turbo* (*Euninella*) sp. cf. *T. (E.) hamiltonensis* Harris arris			x											
38.	*Bolma* (*B.*) *flindersi darraghi* Beu and Ponder			x				x							
39.	*Astralium*? sp.			x											
40.	*Tricolia psilia* Darragh & Kendrick			x											
41.	*Danilia vialis* Darragh & Kendrick			x											
42.	*Agathodonta*? sp.			x											
43.	*Cantharidus armulatus* (Darragh & Kendrick)	x		x		x									
44.	*Clanculus* (s.l.) sp.			x											
45	*Calliostoma* (*Fautor*) *numapum* Darragh & Kendrick	cf		x											
46.	*Calliostoma* (s.l.) sp.			x											
47.	*Carinastele*? sp.			x											
48.	Trochid, gen. undetermined sp. A			x											
49.	Trochid, gen. undetermined sp. B			x											
50.	*Trochaclis*? *stillata* Darragh & Kendrick			x											
51.	*Leucorhynchia rotulina* Darragh & Kendrick		x	x											
52.	*Leucorhynchia ventricosa* Darragh & Kendrick			x											
53.	*Circulus* sp.			x											
54.	*Crosseola princeps* (Tate)			x		x	x					x			
55.	*Clavocerithium kendricki* sp. nov.			x											
56.	*Orthochetus pagoda* (Chapman & Crespin)			x		x		x	x						
57.	*Jetwoodsia nullarborica* (Chapman & Crespin)			x		x		x	x						
58.	*Glyptozaria* sp.			x											
59.	Cerithiid gen. & sp. indeterminate 1			x											
60.	Cerithiid gen & sp. indeterminate 2			x											
61.	Cerithiid gen & sp. indeterminate 3			x											
62.	*Pseudovertagus*? *longbottomi* sp. nov.			x											
63.	*Pseudovertagus*? sp.			x											
64.	*Tenagodus occlusus*? Tenison Woods	x		x		x		x	x		x	x	x	x	x
65.	*Zeacolpus bartoni* Darragh & Kendrick	x	x	x											
66.	*Sirius* sp.			x											
67.	*Cerithioderma tabulata* (Tate)			x		x		x							
68.	*Zoila viathomsoni* Darragh			x											
69.	*Willungia ovulatella* (Tate)			x		x		x	x						
70.	*Phenacovolva* sp.			x											
71.	*Tanea hamiltonensis* (Tenison Woods)			x		x	x	x			x	x	x	x	
72.	*Euspirocrommium*? sp.			x											
73.	Rissoid gen. & spec. indeterminate			x											
74.	*Seraphs* sp.			x											
75.	*Sassia tortirostris* (Tate)			x		x	x	x	x	x	x	x	x	x	x

		A	B		C		D	E					F		G
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
76.	*Triviella pompholugota* (Tate)			x		x		x	x						
77.	*Archierato pyrulata* (Tate)			x		x		x	x	x					
78.	*Thylacodes actinotus* (Tate)			x		x									
79.	*Xenophora* sp.	x		x											
80.	*Notacirsa lampra* (Tate)			x		x		x	x	x					
81.	*Cirsotrema pleiophylla* Tate	cf		x	x	x		x							x
82.	Epitoniid sp.			x											
83.	*Eulima danae* Tenison Woods			x		x	x	x		x		x	x		
84.	*Niso kimberi* Pritchard			x		x		x	x						
85.	*Curveulima*? sp.			x											
86.	*Melanella*? sp.			x											
87.	*Viriola*? sp.			x											
88.	*Mastoniaeforis pagodiformis* sp. nov.		x	x											
89.	*Inella moniliferata* sp. nov.		x	x											
90.	*Inella dauciformis* sp. nov.		x	x											
91.	*Costatophora*? *pulcherrima* sp. nov.			x											
92.	*Seila stenopyrgisca* sp. nov.			x											
93.	*Cerithiopsis pustuloclathrata* sp. nov.			x											
94.	*Cerithiopsis*? sp.			x											
95.	Cerithiopsid sp. 1			x											
96.	Cerithiopsid sp. 2			x											
97.	*Eocolina* sp.			x											
98.	*Ataxocerithium otopleuroides* sp. nov.			x											
99.	*Ataxocerithium venustulum* sp. nov.			x											
100.	*Ataxocerithium multicostulatum* sp. nov.			x											
101.	*Ataxocerithium biaulax* sp. nov.			x											
102.	*Eumetula* sp.			x											
103.	*Trituba* sp.			x											
104.	*Trituba* (*Granulotriforis*) *umboseriata* sp. nov.			x											
105.	*Cerithiella limula* sp. nov.		x	x											
106.	*Cerithiella* sp.			x											
107.	*Tasmeuthria*? *arenicola* sp. nov.			x											
108.	*Retizafra* sp.			x											
109.	*Mitrella* sp.			x											
110.	*Fusinus sculptilis* (Tate)			x		x		x	x						
111.	*Austrolithes* cf. *A. incompositus* (Tate)			x		x		x	x						
112.	*Dennantia aldingensis* (Tate)	x		x		x		x	x						
113.	*Tectifusus aldingensis* (Tate)			x		x		x	x						
114.	*Pugilina*? sp.			x											
115.	*Timbellus calvus* (Tate)			x		x		x	x	x					
116.	*Dermomurex silicatus* sp. nov.			x											
117.	*Dermomurex* sp.			x				x	x						
118.	*Hexaplex*? *tridentatus* (Tate)			x		x		x	x						
119.	*Attiliosa arenaria* sp. nov.			x											

		A	B		C		D	E				F		G
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
120.	*Ocenebra prionotus* (Tate)	?		x		x		x	x	x					
121.	*Coralliophila* (s.l.) sp.			x											
122.	*Laevityphis ludbrookae* Keen & Campbell			x		x		x	x	x					
123.	*Eratoidea fusoides* sp. nov.			x											
124.	*Cryptospira hordeastra* sp. nov.			x											
125.	*Ovaginella mumiformis* sp. nov.			x											
126.	*Ovaginella arenula* sp. nov.			x											
127.	*Serrata* cf. *S. mala* (Cotton)			x		x		x	x						
128.	*Lyria craticulata* sp. nov.			x											
129.	*Mitreola salaputium* Darragh			x											
130.	*Notopeplum* cf. *N. protorhysum* (Tate)	x		x		x		x	x						
131.	*Conomitra strombodiformis* sp. nov.			x											
132.	*Microvoluta* cf. *M. subcrenularis* (Tate)			x		x		x	x						
133.	*Microvoluta* cf. *M. complanata* (Tate)			x		x		x	x						
134.	*Amalda* (*Gracilispira*) *ligata* (Tate)	cf		x		x		x	x						
135.	*Belloliva canaliculata* sp. nov.			x											
136.	*Conus* sp.			x											
137	*Cordieria fuscoamnica* sp. nov.			x				x							
138.	*Cordieria torquata* sp. nov.			x											
139.	*Apiotoma* sp.			x				x							
140.	*Conorbis notialis* sp. nov.			x											
141.	*Splendrillia*? sp.			x											
142.	*Neoguraleus filiferus* sp. nov.			x											
143.	*Comitas silicicola* sp. nov.			x											
144.	*Comitas aldingensis* Powell			x		x		x	x						
145.	*Comitas*? sp.			x											
146.	*Asperdaphne* sp.			x											
147.	*Turehua* sp.			x											
148.	*Semitriton* sp.			x											
149.	*Unitas* sp.			x											
150.	*Heliacus* (*Torinista*) *darraghi* Garrard			x					x	x					
151.	*Tuba* sp.			x											
152.	*Turbonilla* sp.			x											
153	*Pyrgiscus* sp.			x											
154	*Syrnola* sp.			x											
154	*Cylichna* cf *angustata* (Tate & Cossmann)			x		x		x							
	Total gastropods	**10**	**9**	**125**	**1**	**31**	**5**	**32**	**25**	**10**	**3**	**6**	**5**	**3**	**4**
	Scaphopods														
155.	*Fissidentalium mawsoni* (Ludbrook)	x		x		x	x	x	x	x	x	x	x	x	x
	Cephalopods														
156	*Eutrephoceras*? sp.			x											
	Total all molluscs	**18**	**14**	**157**	**3**	**52**	**7**	**43**	**40**	**19**	**5**	**8**	**8**	**4**	**7**

Table 2 shows the number of specimens of each species of gastropod that were collected during the project. It is the relative abundance of each species that is important rather than absolute numbers as the latter is very much an artefact of collecting. The feeding habit of each species was estimated by analogy with living representatives, if such could be found. Not surprisingly, given the sponge rich environment in which the molluscs were living, the fauna is dominated by carnivores that prey on sponges and by other molluscs, such as *Tenagodus*, that are associated with them. Other carnivores that preyed on tunicates also dominate the fauna, suggesting that tunicates were also a significant faunal element. Most tunicates have no hard parts and leave no fossil record, though some species possess spicules that may be fossilised. As yet no such spicules have been recorded from the Pallinup Formation, but Łukowiak (2012) recorded a number of tunicate taxa based on spicules from the Blanche Point Formation. Other significant elements of the molluscan fauna seem to have preyed on cnidarians.

Many shells show signs of hermit crab predation. In the case of *Clavocerithium kendricki* sp. nov. every one of the 469 shells shows damage consistent with crab predation. All specimens of *Pseudovertagus*? *longbottomi* sp. nov., *Ataxocerithium otopleuroides* sp. nov. and *Lyria craticulata* sp. nov. show similar damage. As these species are amongst the most common taxa present in the fauna, hermit crabs must have been an exceedingly common element in the fauna, though few remains of crabs have been found.

TROPHIC COMPOSITION

The reservations about the validity of a trophic analysis expressed in my work on the Pebble Point Formation molluscan fauna (Darragh 1994) apply here; nevertheless, some general remarks are probably valid, particularly since collections were made by sieving matrix. The analysis of the bivalves is based on collections made to 1981, whereas that of the gastropods includes specimens collected subsequently.

TABLE 2 Numbers of specimens of Gastropoda, Scaphopoda and Cephalopoda and feeding type.

Species	Number	Feeding type
Cordieria torquata sp. nov.	1225	Carnivore
Tenagodus occlusus? Tenison Woods	>1000	Suspension feeder
Triviella pompholugota (Tate)	502	Carnivore on tunicates
Clavocerithium kendricki sp. nov.	469	Detritivore
Trituba (*Granulotriforis*) *umboseriata* sp. nov.	366	Carnivore on sponges
Ocenebra prionotus (Tate)	361	Carnivore
Tricolia psilia Darragh & Kendrick	357	Grazer on microbial films on algae & sea grasses
Ataxocerithium multicostulatum sp. nov.	300	Carnivore on sponges
Tanea hamiltonensis (Tenison Woods)	286	Carnivore on molluscs
Eutinochilus otwayensis (Pritchard)	277	?
Willungia ovulatella (Tate)	232	Carnivore on sponges?
Lyria craticulata sp. nov.	231	Carnivore on molluscs
Pseudovertagus? *longbottomi* sp. nov.	208	Detritivore
Hexaplex? *tridentatus* (Tate)	194	Carnivore
Seila stenopyrgisca sp. nov.	191	Carnivore on sponges
Ataxocerithium otopleuroides sp. nov.	182	Carnivore on sponges
Archierato pyrulata (Tate)	179	Carnivore on tunicates
Homalopoma (*H.*) *limnaios* Darragh & Kendrick	177	? Grazer on microbial films
Leucorhynchia rotulina Darragh & Kendrick	175	? Grazer on microbial films
Liotina lamellosa (Tenison Woods)	167	? Grazer on microbial films
Inella moniliferata sp. nov.	142	Carnivore on sponges
Ovaginella mumiformis sp. nov.	140	Carnivore
Calliostoma (*Fautor*) *numapum* Darragh & Kendrick	135	Carnivore on cnidarians or sponges & tunicates
Tasmeuthria? *arenicola* sp. nov.	134	Carnivore
Cryptospira hordeastra sp. nov.	116	Carnivore
Timbellus calvus (Tate)	102	Carnivore
Cantharidus armulatus Darragh & Kendrick	79	Grazer on algal films

Species	Number	Feeding type
Ataxocerithium venustulum sp. nov.	76	Carnivore on sponges
Dennantia aldingensis (Tate)	71	Carnivore on other molluscs
Sassia tortirostris (Tate)	69	Carnivore on ascidians
Neoguraleus filiferus sp. nov.	69	Carnivore
Attiliosa arenaria sp. nov.	57	Carnivore
Notopeplum cf. *N. protorhysum* (Tate)	55	Carnivore
Dermomurex silicatus sp. nov.	53	Carnivore
Conomitra strombodiformis sp. nov.	50	Carnivore
Eulima danae Tenison Woods	49	Parasitic on echinoderms
Ataxocerithium biaulax sp. nov.	47	Carnivore on sponges
Ovaginella arenula sp. nov.	41	Carnivore
Bolma (*B.*) *flindersi darraghi* Beu and Ponder	36	Herbivore or grazer on microbial films
Belloliva canaliculata sp. nov.	33	Carnivore
Cirsotrema pleiophylla Tate	31	Carnivore on cnidarians
Cerithiopsis pustuloclathrata sp. nov.	31	Carnivore on sponges
Cerithiella limula sp. nov.	31	Carnivore on sponges
Coralliophila (s.l.) sp.	30	Carnivore on cnidaria
Conus sp.	29	Carnivore
Eratoidea fusoides sp. nov.	28	Carnivore
Trochaclis? *stillata* Darragh & Kendrick	28	Carnivore on hexactinellid sponges
Cordieria fuscoamnica sp. nov.	26	Carnivore
Comitas silicicola sp. nov.	25	Carnivore
Costatophora? *pulcherrima* sp. nov.	24	Carnivore on sponges
Conorbis notialis sp. nov.	24	Carnivore
Eocolina sp.	23	Carnivore on sponges
Retizafra sp.	23	Carnivore?
Cerithiid genus and species indeterminate 3	22	Detritivore?
Mastoniaeforis pagodiformis sp. nov.	22	Carnivore on sponges
Mitreola salaputium Darragh	22	Carnivore
Jetwoodsia nullarborica (Chapman & Crespin)	19	Detritivore?
Danilia vialis Darragh & Kendrick	19	Carnivore on sponges or sponge microbes
Leucorhynchia ventricosa Darragh & Kendrick	19	? Grazer on microbial films
Inella dauciformis sp. nov.	16	Carnivore on sponges
Amalda (*Gracilispira*) *ligata* (Tate)	15	Carnivore
Fissidentalium mawsoni (Ludbrook)	15	Carnivore on micro-organisms
Zoila viathomsoni Darragh	14	Carnivore on sponges
Melanella? sp.	14	Parasitic on echinoderms
Cerithiella sp.	14	Carnivore on sponges
Dermomurex sp.	12	Carnivore
Microvoluta cf. *M. subcrenularis* (Tate)	12	Carnivore
Zeacolpus bartoni Darragh & Kendrick	11	Suspension and/or deposit feeder
Pugilina? sp.	11	Carnivore on bivalves?
Microvoluta cf. *M. complanata* (Tate)	11	Carnivore
Orthochetus pagoda (Chapman & Crespin)	10	Deposit feeder?
Eumetula sp.	9	Carnivore on sponges
Emarginula? sp.	9	Carnivore on sponges?
Glyptozaria sp.	8	Suspension and/or deposit feeder
Seraphs sp.	8	Deposit feeder?
Mitrella sp.	8	Carnivore on polychaetes & ascidians
Comitas aldingensis Powell	8	Carnivore
Comitas? sp.	8	Carnivore

Species	Number	Feeding type
Splendrillia? sp.	7	Carnivore
Asperdaphne sp.	7	Carnivore
Viriola? sp.	6	Carnivore on sponges
Clanculus (s.l.) sp.	6	Herbivore
Cerithiid genus and species indeterminate 2	5	Detritus feeder?
Curveulima? sp.	5	Parasitic on echinoderms
Angaria (*Pseudoninella*)? sp.	5	Herbivore?
Calliostoma (s.l.) sp.	5	Carnivore on cnidarian, sponges & tunicates
Euspirocrommium? sp.	4	Grazer on macroalgae?
Cerithiopsis? sp.	4	Carnivore on sponges
Turehua sp.	4	Carnivore?
Semitriton sp.	4	Carnivore?
Turbonilla sp.	4	Parasite on polychaetes or molluscs
Pseudovertagus? sp.	3	Deposit feeder?
Pyrgiscus sp.	3	Parasite on polychaetes or molluscs
Cylichna cf *angustata* (Tate & Cossmann)	3	Carnivore feeding on foraminifera
Turbo (*Euninella*) sp. cf. *T. (E.) hamiltonensis* Harris	3	Herbivore?
Trochid, genus undetermined Species B	3	?
Circulus sp.	3	Grazer on algal and bacterial films
Cerithiid genus and species indeterminate 1	2	?
Cerithioderma tabulata (Tate)	2	Filter feeder
Notacirsa lampra (Tate)	2	Carnivore on cnidarians
Niso kimberi Pritchard	2	Parasite on echinoderms
Trituba sp.	2	Carnivore on sponges
Serrata cf. *S. mala* (Cotton)	2	Carnivore
Syrnola sp.	2	Parasite on polychaetes or molluscs
Nacella? *jutsoni* (Chapman and Crespin)	2	Grazer on microalgae and diatoms on hard surfaces?
Sirius sp.	1	Filter feeder
Phenacovolva sp.	1	Carnivore on cnidarians
Rissoid genus and species indeterminate	1	?
Thylacodes actinotus Tate	1	Filter feeder
Xenophora sp.	1	Herbivore
Epitoniid sp.	1	Carnivore on cnidarians
Cerithiopsid sp. 1	1	Carnivore on sponges
Cerithiopsid sp. 2	1	Carnivore on sponges
Fusinus sculptilis (Tate)	1	Carnivore
Austrolithes cf. *A. incompositus* (Tate)	1	Carnivore?
Tectifusus aldingensis (Tate)	1	Carnivore?
Laevityphis ludbrookae Keen & Campbell	1	Carnivore
Apiotoma sp.	1	Carnivore
Unitas sp.	1	Carnivore
Heliacus (*Torinista*) *darraghi* Garrard	1	Carnivore on cnidarians
Tuba sp.	1	Carnivore on cnidarians
Eutrephoceras? sp.	1	Pelagic carnivore
Astralium? sp.	1	?
Agathodonta? sp.	1	? Grazer on microbial films on hard substrates
Carinastele? sp.	1	Carnivore?
Crosseola princeps (Tate)	1	?
Trochid, genus undetermined Species A	1	?
Total	**9,440**	

BIVALVES

Of the 30 bivalve species in the fauna, represented by 772 specimens, five (*Limopsis chapmani*, *Saccella chapmani*, *Arcopsis dissimilis*, *Plicatula emaciata* and *Venericardia* (*Rotundicardia*) *latissima*) dominate the assemblage in terms of numbers of specimens collected (621) and relative abundance (80% of the total number). Of these species, 44% are infaunal, suspension feeding bivalves, 36% are epifaunal, suspension feeding bivalves and 20% are infaunal deposit feeding bivalves. Overall there are 470 specimens of infaunal bivalves and 290 epifaunal bivalves (ignoring some specimens of indeterminate affinity).

Generalised grouping of species according to feeding type and habitat

Infaunal deposit feeding
Saccella chapmani, *Nucula tatei*, *Sarepta planiuscula.*

Infaunal suspension feeding
Limopsis chapmani, *Limopsis multiradiata*, *Tucetona lenticularis*, *Epicodakia* sp., *Venericardia* (*Rotundicardia*) *latissima*, *Salaputium communis*, *Glossus* (*Miocardiopsis*) sp., *Dosina multilamellata*, *Corbula* (*Caryocorbula*) *pixidata.*

Epifaunal, byssate, suspension feeding
Arcopsis dissimilis, *Barbatia* (*B.*) *limatella*, *Arca pseudonavicularis*, *Barbatia* (*Acar*) *gunsoni*, *Septifer* sp.

Epifaunal, attached, suspension feeding
Plicatula (*P.*) *emaciata*, *Dimya sigillata*, *Vulsella laevigata*, *Spondylus gaderopoides.*

Infaunal carnivore
Verticordia sp. A, *Verticordia* sp. B.

OTHER MOLLUSCS (SEE TABLE 2)

There are 105 genera of gastropods, one scaphopod and one cephalopod for which feeding habits can be estimated with reasonable certainty and which are represented by about 9160 specimens. Seventy genera (67%) are carnivores, 15 genera (13%) are grazers, 9 genera (9%) are detritivores, 7 genera (7%) are parasites and 5 genera (4%) are suspension feeders. In terms of percentages of total number of specimens collected 69% are carnivores, 11% are grazers, 8% are detritivores, 0.9% are parasites and 11% are suspension feeders. The latter percentage may be slightly inaccurate as it is not possible to give precise numbers of specimens of *Tenagodus* of which there are slightly in excess of 1000 as many are broken, but still this suspension feeder amounts to the second most common species collected. Overall the fauna is dominated by carnivores both in terms of number of taxa and number of specimens.

Of the carnivores, 19 genera (18% of all genera) are associated with sponges, which is 27% of the carnivore genera. In terms of numbers of specimens of these taxa, there are 1825 specimens amounting to 20% of all specimens collected and 29% of the total carnivore specimens. Large and small specimens of siliceous sponges are a very common element of the fauna in the Pallinup Formation and many specimens of *Tenagodus* are found within sponges. The sponges are yet to be studied in detail.

Carnivores on tunicates and cnidarians are also present in high proportions (Table 2), which suggests that tunicates and cnidarians were significant elements of the fauna. Some fragmentary silicified skeletal remains of cnidarians occur in the fauna, but they have not yet been studied.

The parasitic molluscs comprise two groups: eulimids which parasitise echinoderms and pyramidellids which parasitise polychaetes or molluscs. Echinoderms are not common in the Pallinup Formation at Walpole and are represented mostly by regular echinoid spines belonging to *Stylocidaris*, *Eucidaris*, and possibly *Stereocidaris* (personal commmunication K. McNamara). However, a number of irregular echinoids have also been recorded, namely species of *Linthia, Schizaster, Prenaster, Giraliaster* and *?Pericosmus* (McNamara 1985).

GENERALISED GROUPINGS (BASED ON TABLE 2).

Genera are arranged according to species abundance.

Grazers

Tricolia, *Homalopoma*, *Leucorhynchia*, *Liotina*, *Cantharidus*, *Bolma*, *Clanculus*, *Angaria*, *Circulus*, *Euspirocromium*, *Turbo*, *Nacella*, *Xenophora.*

Suspension feeders

Tenagodus, *Seraphs*, *Cerithioderma*, *Sirius*, *Thylacodes.*

Detritivores

Clavocerithium, *Pseudovertagus*, *Jetwoodsia*, *Zeacolpus*, *Orthochetus*, *Glyptozaria.*

Parasites

Eulima, *Melanella*, *Curveulima*, *Turbonilla*, *Pyrgiscus*, *Niso*, *Syrnola.*

Pelagic carnivores

Eutrephoceras.

Carnivores

Cordieria, *Triviella*, *Granulotriforis*, *Ocenebra*, *Ataxocerithium*, *Tanea*, *Willungia*, *Lyria*, *Hexaplex*, *Seila*, *Archierato*, *Inella*, *Ovaginella*, *Calliostoma*, *Tasmeuthria*, *Cryptospira*, *Timbellus*, *Denanntia*, *Sassia*, *Neogularaeus*, *Attiliosa*, *Notopeplum*, *Dermomurex*, *Conomitra*, *Belloliva*, *Cirsotrema*, *Cerithiopsis*, *Cerithiella*, *Coralliophila*, *Conus*, *Eratoidea*, *Trochaclis*, *Comitas*, *Conorbis*, *Eocolina*, *Retizafra*, *Mastonaeforis*, *Mitreola*, *Danilia*, *Gracilispira*, *Fissidentalium*, *Zoila*, *Microvoluta*, *Pugilina*, *Eumetula*, *Emarginula*,

Mitrella, *Comitas*, *Splendrillia*, *Asperdaphne, Viriola*, *Calliostoma*, *Turehua*, *Semitriton*, *Cylichna*, *Notocirsa*, *Trituba*, *Phenacovolva*, *Fusinus*, *Austrolithes*, *Tectifusus*, *Laevityphys*, *Apiotoma*, *Unitas*, *Heliacus*, *Tuba*, *Carinastele*.

BIOGEOGRAPHY

Valid biogeographic conclusions rely on correct generic assignments of the taxa in the fauna as well as on accurate geographical records of the genera. Many of the species in the Walpole fauna are assigned to genera with a query, so it could be argued that it is not possible to come to any biogeographic conclusions. However, most of the taxa with these questionable assignments are very similar to other species in the genus or to other genera in the family, so an assignment to a particular biogeographic element is probably correct in most cases. Given the number of genera involved (about 130), broad conclusions can be drawn which have some validity. Another factor which may affect conclusions is the high number of taxa that seem to be endemic to the fauna. About 33 genera (25.5%) present in the fauna are not known from Eocene or later faunas in eastern Australia. There are two possible reasons for this: faunas from environments rich in sponges do not seem to be represented elsewhere; and many of the taxa, particularly those small in size, belong to groups of molluscs not yet studied from other Australian formations but possibly present in them. Of the other genera, 64 (49%) are known from other Eocene formations in eastern Australia and 33 (25.5%) are known from younger formations in eastern Australia. Overall about 74% of the genera are found in the Southern Australian Province (Darragh and Kendrick 2008), so it is concluded that the Eucla Basin during the late Eocene was within that province which at that time extended from the southern Carnarvon Basin to the Gippsland Basin.

In terms of biogeographic origins of the Walpole fauna using criteria outlined by Darragh (1985), 11.5% of the genera are of the Australia-New Zealand element, 57% are of the Tethyan Indo-Pacific element, 13% are of the Southern Australian Endemic element and 18.5% are cosmopolitan. These percentages can be compared with the proportions of the biogeographic elements for the eastern Australian Eocene cited by Darragh (1985), 26%, 25%, 24% and 25% respectively, where each element comprised about a quarter of the fauna. It will be seen that the Tethyan Indo-Pacific element in the Walpole fauna comprises over half the fauna, which is probably explained by the high proportion of the endemic taxa having a Tethyan Indo-Pacific origin.

McGowran et al. (1997) argued that the Leeuwin Current that moves south along the western coast of Western Australia and sweeps east around the southern coast originated in the late middle Eocene, bringing warm water faunas from the north to the southern coast. Of significance to this argument is the presence of *Seraphs* in the Pallinup Formation, whereas it is not present in eastern Australia. Other genera that are found in the Pallinup Formation but only occurred in eastern Australia later in the mid-Tertiary thermal maximum include *Plicatula*, *Glyptozaria*, *Xenophora*, *Zoila, Phenacovola*, *Lyria* and *Conus*. An explanation for the high proportion of the Tethyan Indo-Pacific element at Walpole but not in the eastern Australian faunas might be provided by the influence of the Leeuwin Current that weakens to the east and so has less influence on the faunas there.

SIMILAR FOSSIL FAUNAS

Molluscan faunas associated with sponges such as that of the Pallinup Formation seem to be exceedingly rare in the Tertiary sequence. A fauna with somewhat similar molluscan taxa occurs in the Danian Faxe Formation of Denmark (Lauridsen and Schnetler 2014). However, the Faxe Formation is a cool water carbonate deposit with coral and bryozoan mounds, said to be deposited at depths of 200–400 metres, and thus represents a fundamentally different environment from that of the Pallinup Formation. Nevertheless, the occurrence in the Faxe Formation of similar genera of molluscs, particularly representatives of the Triphoridae, Cerithiopsidae and Newtoniellidae, is surprising and perhaps reflects the presence of cnidarians and sponges in both formations.

SYSTEMATIC PALAEONTOLOGY

The arrangement of families follows Bouchet and Rocroi (2005) with the exception of the former Family Turridae where the arrangement is according to Bouchet *et al.* (2011). The authors of all generic and higher taxa are based on information from the World Register of Marine Species (WoRMS) [http://www.marinespecies.org/index.php], which provides full bibliographic references for each taxon as well as type species of genera and such details are not repeated here.

Australian Map Grid references are cited from Western Australian 1:100,000 maps, Deep River for the North Walpole locality and Merivale for Cape Le Grand National Park localities.

Institutional abbreviations are as follows:

NMV P Museum Victoria Palaeontological Collection.

SAM T South Australian Museum Tate Collection.

WAM Western Australian Museum.

Class Gastropoda Cuvier, 1797

Vetigastropoda

Family Crosseolidae Hickman, 2013

Genus *Crosseola* Iredale, 1924

Crosseola princeps (Tate, 1890)

Figure 1.36

Crossea princeps Tate, 1890: 220; Tate, 1891, plate 8, figures 6a–b.

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Australian Map Grid, Deep River 743 486. 1 specimen (WAM 69.165).

DESCRIPTION

Shell small (3 mm), turbinate, of four regularly convex whorls. Protoconch of one smooth whorl coiled in axis of shell. Sculpture of very fine, close-set lirae present over entire whorl, interspaces pitted. Aperture subcircular with outer lip thickened into a prominent rounded varix; aperture notched anteriorly forming a short shallow canal. Pseudumbilicus present bounded by a strongly developed umbilical keel sculptured like the whorls.

DIMENSIONS

	Height	Width	No. of whorls
WAM 69.165	3.0	2.6	4

REMARKS

Although somewhat damaged the single specimen is sufficiently well preserved to enable determination. This species is very similar to *Crosseola concinna*, Recent, south-eastern Australia, but differs in having more numerous and finer lirae, a more prominent pseudumbilicus and the early whorls do not possess a keel.

OCCURRENCE

Eucla Basin: Pallinup Formation. **St Vincent Basin**: Blanche Point Formation (type). **Murray Basin**: Cadell Marl. **Otway Basin**: Muddy Creek Formation.

Caenogastropoda

Family Cerithiidae Fleming, 1822

Genus *Clavocerithium* Cossmann, 1920

Clavocerithium kendricki sp. nov.

Figures 1.1–3, 1.19

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MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** WAM 69.135 from Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486.

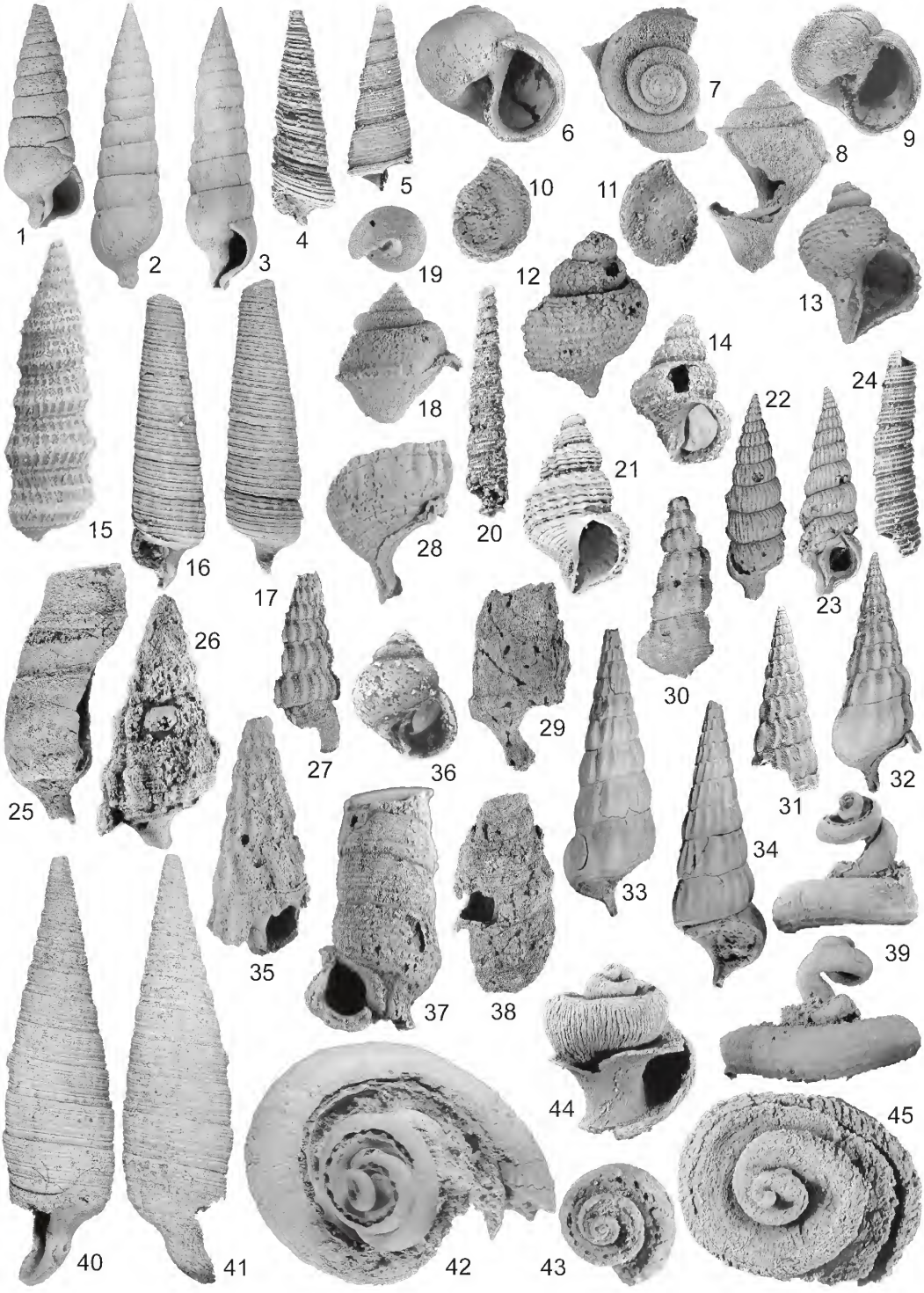
Paratypes

WAM 72.252, NMV P329330 from type locality.

Other material

From type locality: 466 specimens (WAM 67.117, 67.174, 69.196, 72.240, 72.258, 72.320–1, 79.1015, 82.1482, 99.164, 99.222, 04.145a, 10.12; NMV P302225, P302226–8, P317172).

FIGURE 1 1, 2, 3, 19, *Clavocerithium kendricki* sp. nov.: 1, 19, WAM 72.252 (x 2) paratype; 2, 3, WAM 69.125 (x2) holotype;
4, 16, 17, 40, 41, *Pseudovertagus longbottomi* sp. nov.: 4, WAM 67.109 (x 2) paratype; 16, 17, WAM 67.171 (x2) paratype; 40, 41, WAM 79.1014 (x2) holotype;
5, *Zeacolpus bartoni* Darragh & Kendrick, 2008: 5, WAM 07.190a (x3) Lucky Bay;
6, 9, *Tanea hamiltonensis* (Tenison Woods, 1879): 6, WAM 12.02 (x 5); 9, WAM 12.01 (x 5);
7, 8, 18, *Euspirocrommium?* sp.: 7, 18, WAM 99.208 (x3); 8, WAM 12.06 (x 1.5);
10, 11, *Naticid operculum*: 10 (internal), 11 (external), WAM 12.04 (x7);
12, 13, *Sirius* sp.: 12, 13, WAM 99.221 (x 8);
14, 21, *Cerithioderma tabulata* (Tate, 1890): 14, WAM 69.171 (x 5); 21, SAM T766 (x 5) holotype, Adelaide bore;
15, *Orthochetus pagoda* (Chapman & Crespin, 1934): 15, WAM 05.34 (x 4) Lucky Bay;
20, 24, *Glyptozaria* sp.: 20, WAM 15.51 (x 5); 24, WAM 15.52 (x 5);
22, 23, 27, 28, 30, 31, 32, 33, 34, 35, *Jetwoodsia nullarborica* (Chapman & Crespin, 1934): 22, 23, WAM 12.71 (x 1.5); 27, 30 NMV P14631 (x 3) paratype, Cape Riche; 28, WAM 99.226c (x 2); 31, NMV P13675 (x 3) paratype, Blanche Point; 33, 34, NMV P13674 (x 1.25) holotype, Blanche Point; 35, WAM 99.226b (x 2);
25, *Cerithiid* sp. 1: 25, WAM 99.225 (x 1.5);
26, 29, 38, *Cerithiid* sp. 2: 26, WAM 99.163 (x 1.5); 29, WAM 99.224b (x 1); 38, WAM 99.224a (x 1);
36, *Crosseola princeps* (Tate, 1890): 36, WAM 69.165 (x 8);
37, *Pseudovertagus* sp.: 37, WAM 80.1340 (x 3) Cape Le Grand;
39, 42, 43, 44, 45, *Tenagodus occlusus?* Tenison Woods, 1877: 39, 42, WAM 09.05a, 38, 39 (x 2), 42 (3); 43, WAM 09.01 (x 4); 44, 45, WAM 09.05b (x 3).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Cape Le Grand National Park, old track surface, 3.7 km south-east of Frenchman Peak, near road to Lucky Bay, 2 specimens. (WAM 80.1336, 85.1451). Total 469 specimens.

DIAGNOSIS

Shell cyrtoconoid with three weakly beaded lirae on abapical spire whorls, remainder of shell smooth. Siphonal fasciole prominent.

DESCRIPTION

Shell elongate, cyrtoconoid, whorls very slightly convex, 10 to 15 teleoconch whorls. Sutures impressed. Protoconch of 2½ smooth, convex whorls, first whorl deviated slightly from axis of shell, second whorl with slight peripheral keel on some specimens, merging rapidly into first teleoconch whorl. First three to five teleoconch whorls sculptured with three very weakly beaded, thick lirae, interspaces about as wide as lirae, remainder of teleoconch whorls smooth. Aperture lenticular, produced anteriorly into a short right twisted canal. Outer lip sinuous, opisthocline. Columella covered with callus, developed into thick plate on some specimens. Right raised edge of canal angulation forming a prominent ridge extending up the spire. Siphonal fasciole prominent.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 69.135, holotype	26.0	6.5	6.5	16
WAM 72.252, paratype	21.0	7.5	3.8	11 spire broken
NMV P329330, paratype	17.2	5.0	3.0	12

ETYMOLOGY

This species is named in memory of my late friend and colleague George Kendrick, formerly of the Palaeontology Department of the Western Australian Museum, who first discovered the silicified mollusc fauna at North Walpole and with whom I enjoyed several field seasons collecting fossils there and at other places in Western Australia.

REMARKS

This is one of the most common species of gastropod in the fauna, yet not one specimen has a complete aperture. All specimens with the last whorl preserved have damage consistent with crab attack. Many specimens also have evidence of earlier mended fractures on the spire. A few specimens have gastropod boreholes.

The morphology of the teleoconch is very similar to the type species of the genus, *Clavocerithium lacazei* (Vasseuer, 1881), Eocene, France, but that species has a uniformly tapering spire and a weak siphonal fasciole.

There is nothing like this species present in any of the other Australian Tertiary formations.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Genus *Orthochetus* Cossmann, 1889

Orthochetus pagoda (Chapman and Crespin, 1934)

Figure 1.15

Mathilda pagoda Chapman and Crespin, 1934:122, plate 11, figures 29–30.

Orthochetus pagoda (Chapman and Crespin): Darragh, 2011a: 39, Figures 3A–R.

MATERIAL EXAMINED

Australia: ***Western Australia*:** Pallinup Formation. Gardner River, 1 specimen, external mould (WAM 75.142); nine miles east of Northcliffe, west side of Eggling Rd., quartz gravel excavation, 1 specimen (WAM 69.266); Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486, 4 specimens (WAM 10.02, 10.11; NMV P317171); Albany, 1 paratype; Lucky Bay, via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay 1 specimen (WAM 05.34); Cape Le Grand National Park, Merivale 428 219, 2 specimens (WAM 07.191, 80.1339). Total 10 specimens.

DESCRIPTION

Shell turreted, pagodiform, of average size for genus (30–40 mm high), with imbricate whorls bearing prominent keel and fenestrate sculpture; spire angle about 20°. Protoconch of 1–1.5 whorls, first whorl smooth, swollen and deviated at right angles to axis of shell; second whorl with thin, close-set axial lamellae extending across whole whorl. Spiral sculpture begins on first teleoconch whorl. Teleoconch whorls with prominent keel situated at anterior ¾ of whorl, which bears one prominent cord. Spiral sculpture of three fine lirae posterior to keel and one fine lira anterior to keel and adjacent to anterior suture. Axial sculpture of fine, regularly spaced costae, tuberculate at intersections with spiral lirae, forming a fenestrate pattern on posterior half of spire. Towards aperture, costae become crowded together and less distinct. Last whorl abruptly contracted anterior to keel, bearing one prominent cord and simple thin lirae; low somewhat coarse lirae on canal. Aperture subrectangular with

prominent columella plate, produced into short narrow anterior canal, weak posterior notch. Single plait present at beginning of canal.

REMARKS

This species has been dealt with in detail by Darragh (2011a). Some additional occurrences are recorded here. The species is rare in Western Australia and all specimens are fragmentary and usually crushed.

OCCURRENCE

Eucla Basin: Pallinup Formation. **Saint Vincent Basin**: Blanche Point Marl (type). **Otway Basin**: Browns Creek Formation.

Genus *Jetwoodsia* Ludbrook, 1971

Jetwoodsia nullarborica (Chapman and Crespin, 1934)

Figures 1.22–23, 1.27–28, 1.30–35

Potamides nullarboricum Chapman and Crespin, 1934:123, plate 11, figures 31–3.

Jetwoodsia nullarborica (Chapman and Crespin): Ludbrook, 1971: 39, plate 6, figures 4–5.

MATERIAL EXAMINED

Holotype

Australia: *South Australia*: NMV P13674 from Blanche Point Marl, Aldinga.

Paratypes

NMV P13675 from type locality. NMV P14631 ***Western Australia*:** Pallinup Formation. Cape Riche.

Other material

Australia: *Western Australia*: Pallinup Formation. Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486, 9 specimens (WAM 67.115, 72.286, 99.226b–c, 12.71; NMV P323140–1); Lucky Bay, via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, 1 specimen (WAM 05.35); Cape Le Grand National Park, Merivale 428 219, 4 specimens (WAM 06.159, 07.189). Mt Barker, Plantagenet Location 6128, west side Barrow Rd, 2 specimens (WAM 84.1033 a-b)? Little Wharton Bay near Mt Belches, Duke of Orleans Bay, Lat. 33° 56' 55"S, Long 122° 34' 28" E, 1 specimen (WAM 05.173a). Cape Riche, 1 specimen (NMV P14631)? Total 18 specimens.

DESCRIPTION

Shell of small size for genus, turreted with 11–12 slightly convex whorls. Protoconch of 2½ smooth whorls, coiled in axis of shell, merging abruptly with teleoconch whorls. Axial sculpture of about 16–18 low, thin costae, much narrower than interspaces, extending from suture to suture and becoming obsolete on last whorl. Occasional broad varices present on whorls. Last whorl with two varices about 120° apart; one varix behind outer lip. Spiral sculpture of very fine, weak threads. Aperture with deep posterior notch, outer lip reflected dorsally, columella covered with thick glaze. Siphonal canal short, reflexed dorsally.

DIMENSIONS

	Height	Width	No. of whorls
NMV P13674, holotype	33.9	11.5	10+ spire broken
NMV P13675, paratype	11.3	4.1	10+ spire broken
NMV P14631, paratype	c. 14.4		
WAM 07.189A	29.1	10.6	12+ spire broken and shell slightly crushed
WAM 12.71	25.4	7.6	11+ spire broken and shell slightly crushed
WAM 99.226b	21.8	10.0	8+ specimen broken
WAM 99.226c	15.0	12.6	broken last whorl

REMARKS

Specimens from Walpole, Lucky Bay and Cape Le Grand have slightly more convex whorls than those from the type locality, but otherwise match the type material closely. The specimens from Cape Riche and Mt Barrow are external moulds and seem to have more prominent spiral sculpture than the other Eucla Basin material, but the preservation of this material leaves some doubt about the identifications. Browns Creek specimens have very weak axial plicae, more or less restricted to the area below the posterior suture.

OCCURRENCE

Eucla Basin: Pallinup Formation. **Saint Vincent Basin**: Blanche Point Marl (type). **Otway Basin**: Browns Creek Formation.

Genus *Glyptozaria* Iredale, 1924

Glyptozaria sp.

Figures 1.20, 1.24

MATERIAL EXAMINED

Australia: *Western Australia*: Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. 6 specimens (WAM 69.132, 15.51–3, NMV P329280, P329282). Cape Le Grand National Park, old track surface, 3.7 km south-east of Frenchman Peak. 1 specimen (WAM 80.1334). Total 8 specimens.

DESCRIPTION

Shell turriculate, whorls rounded with impressed sutures. Spiral sculpture of four widely spaced lirae. Axial sculpture of very thin, widely spaced threads. Aperture subcircular.

DIMENSIONS

	Height	Width	No. of whorls
WAM 15.51	8.4	1.5	11+ specimen broken
WAM 15.52	7.5	1.4	8+ specimen broken

REMARKS

All the specimens are very poorly preserved and broken. This species differs from *Glyptozaria transenna* (Tenison Woods, 1879), Middle Miocene, Otway Basin, Victoria, by having much narrower and more regularly rounded whorls. From *G. opulenta* (Hedley, 1907), Recent, eastern Australia, it differs by having finer and less cancellate sculpture.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Cerithiid genus and species indeterminate 1

Figure 1.25

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 99.225; NMV P317174. Total 2 specimens.

DESCRIPTION

Shell turriculate, whorls flat to very slightly concave, smooth. Whorls very slightly stepped.

DIMENSIONS

	Height	Width	No. of whorls
WAM 99.225	31.8	13	3+ specimen broken

REMARKS

The available material is too poor for precise description and determination. Both specimens lack posterior whorls. The preserved anterior portion of the last whorl present on the figured specimen suggests the possible presence of a canal. There is nothing like this species present in Eocene formations of south-eastern Australia.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Cerithiid genus and species indeterminate 2

Figures 1.26, 1.29, 1.38

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. (WAM 99.163, 99.224; NMV P317187). Total 5 specimens.

DESCRIPTION

Fragmentary specimens of at least five whorls with weak shoulder. Sculpture of fine lirae, interspaces equal in width to lirae. Axial sculpture of prominent elongate nodules running from shoulder to anterior suture, about nine per whorl.

DIMENSIONS

	Height	Width	No. of whorls
WAM 99.163	30.7	15	5+ specimen broken
WAM 99.224a	36.4	19	4+
WAM 99.224b	34.4	18.5	3+

REMARKS

The available material is too poor for precise description and determination.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Cerithiid genus and species indeterminate 3

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 99.173, 99.226a; NMV P302234. Total 22 specimens.

DESCRIPTION

Fragmentary specimens. Spire turriculate with slightly rounded whorls. Protoconch of one axially plicate whorl merging imperceptibly into teleoconch whorls, coiled in axis of shell. First teleoconch whorls axially plicate. Plicae developing into broad costae by second teleoconch whorl; about 12 costae per whorl on mid spire. Spiral sculpture of fine lirae, much narrower than interspaces, becoming wider and more irregular in width on last whorl.

REMARKS

The available material is too poor for precise description and determination. The specimens consist of several small juvenile specimens, some of which may not belong to this species, but poor preservation prevents certainty.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Genus *Pseudovertagus* Vignal, 1904

Pseudovertagus? longbottomi sp. nov.

Figures 1.4, 1.16–17, 1.40–41

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MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** WAM 79.1014 from Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486.

Paratypes

WAM 67.109; 67.171, NMV P329331 from type locality.

Other material

196 specimens from type locality (WAM 67.112, 67.116, 69.154, 72.288, 72.290?, 99.162, 99.223–4, 10.13; NMV P302229, P302230, P302231, P302232, P317173). Cape Le Grand National Park, via Esperance, old track surface 3.7 km south-east from Frenchman Peak, 5 specimens (WAM 80.1325, 80.1338); Lucky Bay, via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, Merivale 264386, 4 specimens (WAM 05.38). Total 208 specimens.

DIAGNOSIS

Shell sinistral with 6–10 flat, ribbon-like lirae with irregular low axial folds.

DESCRIPTION

Shell sinistral, elongate turriteliform. Protoconch of about two smooth whorls, first whorl globose, deviated about 90° to axis of shell, second whorl convex and merging rapidly into first teleoconch whorl. First teleoconch whorl with three thick lirae, which continue and flatten by fourth or fifth whorl. Whorls flat 14–16+. Spiral sculpture of 6–10 flat, ribbon-like lirae of varying width, separated by shallow grooves. Lirae bearing irregular, low axial folds which give spiral sculpture an undulatory appearance. Aperture, subcircular, produced into an almost closed posterior notch, anteriorly produced into medium length canal, almost closed and dorsally reflexed. Columella covered with thick callus forming a plate.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 79.1014, holotype	39	10.2		14+ juvenile whorls broken off
WAM 67.171, paratype	26.5	7.1	3.6	9+ specimen crushed
WAM 67.109, paratype	9.8	2.8		10+ protoconch
NMV P329331, paratype	41.7	9.5	c.4.0	16+ specimen crushed

ETYMOLOGY

This species is named for Alan F. Longbottom of Grass Patch, Western Australia, in recognition of his assistance in collecting at North Walpole and who collected many specimens for the project at Lucky Bay and Cape Le Grand.

REMARKS

Most of the specimens are fragmentary and many specimens are crushed. All specimens with the last whorl preserved have damage consistent with crab attack. Only one specimen has a reasonably well preserved aperture. Assignment to the genus *Pseudovertagus* is tentative, because of the sinistral nature of the shell, however, it bears some resemblance to the dextrally coiled Indo-Pacific species *P. nobilis* (Reeve, 1855). Sinistral marine shells are very rare and none are known in the Cerithioidea. Only species in the family Triphoridae are consistently sinistral. The members of this family are small and it is most unlikely that this large species would belong in the family. The species probably represents a new genus, but given the quality of preservation and lack of a complete aperture on any specimen, it seems unwise to erect a new genus for the species. There is no other similar species recorded from the Tertiary of Australia.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Pseudovertagus? sp.

Figure 1.37

MATERIAL EXAMINED

Australia: ***Western Australia*:** Cape Le Grand National Park, via Esperance, old track surface 3.7 km south-east from Frenchman Peak, 1 specimen (WAM 80.1340); Lucky Bay, via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, Merivale 264386, 1 specimen (WAM 04.186); Little Wharton Bay, near Mt Belches, Duke of Orleans Bay, 1 specimen (WAM 05.174). Total 3 specimens.

DESCRIPTION

Shell sinistral, with slightly convex whorls. Axial sculpture of close-set lirae of somewhat irregular width, about eight on penultimate whorl and 10–11 on last whorl. Aperture somewhat D shaped, posterior notch closed and forming a short tube, anterior canal short and narrow (poorly preserved).

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 80.1340	14.8	7.5	3.5	3½ whorls preserved

REMARKS

All specimens are broken, so it is not known how many whorls an adult shell possessed nor the morphology of the protoconch and early whorls. This species bears a close resemblance to *Pseudovertagus*? *longbottomi* sp. nov., but the whorls are more rounded and there is no trace of axial sculpture.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Family Siliquariidae Anton, 1838

Genus *Tenagodus* Guettard, 1770

Tenagodus occlusus? Tenison Woods, 1877

Figures 1.39, 1.42–45, 2

?*Tenagodus occlusus* Tenison Woods, 1877: 100.

Tenagodus sp. Darragh and Kendrick, 2008: 233, Figures 2.11, 2.15.

MATERIAL EXAMINED

Australia: *Western Australia*: Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. 1000+ specimens (WAM 67.110, 69.134, 72.239, 72.256, 72.282–3, 99.175–6, 99.219-20, 99.227, 99.229–234, 04.157, 09.04–5, 15.266–7, plus numerous unregistered specimens. NMV P302219–4, P329334–7). Lucky Bay, via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, Merivale 264386, 1 specimen (WAM 05.56 cast); 19 km south of Jerramongup near the Eucla River. WAM 71.1032 1 specimen; 14.5 km east of Northcliffe, gravel pit west side of Eggling Rd., Pemberton 428724. 2 specimens (WAM 69.267, 69.273). Total 1000+ specimens.

DESCRIPTION

Shell irregular, early whorls loosely coiled, later whorls, loosely to irregularly coiled. Protoconch of 1¼ whorls merging abruptly with teleoconch. Sculpture of beaded, longitudinal ribs or threads. On some specimens very faint, on others coarse, becoming stronger adapically, widely spaced or crowded. Slit consisting of a series of holes, sealed on the early whorls.

DIMENSIONS

	Height	Width	No. of whorls
WAM 09.05a	18.2	18.8	5½+ specimen broken
WAM 09.05b	10.8	10.2	3½+ specimen broken
WAM 15.266	5.5	6.4	3 specimen broken
WAM 71.1032	85		

REMARKS

This is by far the most common mollusc found at the Thomson Road locality. Specimens range from small specimens to large fragments up to 8 mm whorl diameter. Some specimens are found still embedded within lithistid sponges, but the majority of the material consists of loose broken specimens of varying lengths, which may or may not have the early whorls preserved. It was first thought there were two species present in the material, one species having a simple open slit with smooth sides and the other having a slit formed from a series of holes, however, on close examination it is not always possible to prove that the slit consistently has smooth sides so probably only one species is present. Specimen number WAM 71.1032 (Figure 2) is a cast of a sponge that was inhabited by two large specimens of *Tenagodus*, probably of this species.

Large Walpole specimens closely resemble specimens from Fossil Bluff, Tasmania, the type locality of *Tenagodus occlusus* Tenison Woods, 1877. The latter specimens also seem to vary in the development of the slit, so the Walpole species has been included in that taxon, but with a query. Somewhat similar but much rarer material of this species is found in the late Eocene unnamed sandstone near Kalbarri, Blanche Point Formation and in the Browns Creek Formation. The species also occurs in Miocene formations in South Australia, Tasmania and Victoria, but nowhere as common as at the Thomson Road locality.

Based on a sample sent to him, Dr Andrjez Pisera (personal communication, August 2016) stated that: 'Unfortunately, the silicification is very gross thus it is not possible to tell the genus of the lithistid as details of the desmas are not well preserved (also because ectosomal spicules are absent). It can be both theonellid as well as corallistid — looking at gross morphology of desmas. Today, such gastropods are associated mostly with theonellids, and I have never heard of corallistids in such association. Taking into account that such gastropods are rather shallow, deep water association with corallistids is less probable'.

OCCURRENCE

Southern Carnarvon Basin: unnamed sandstone. **Eucla Basin**: Pallinup Formation. **St Vincent Basin**: Blanche Point Formation. **Murray Basin**: Cadell Marl; **Bass Basin**: Freestone Sandstone (type). **Otway Basin**: Browns Creek Formation; Fyansford Formation.

FIGURE 2 *Tenagodus occlusus?* Tenison Woods, 1877: WAM 71.1032 (x 0.9) 19 km S of Jerramongup.

Family Turritellidae Lovén, 1847

Genus *Zeacolpus* Finlay, 1926

Zeacolpus bartoni Darragh & Kendrick, 2008

Figure 1.5

Zeacolpus bartoni Darragh and Kendrick, 2008: 232, Figures 3.8, 3.9, 3.10, 3.32.

MATERIAL EXAMINED

Australia: *Western Australia*: Cape Le Grand National Park, via Esperance, old track surface 3.7 km south-east from Frenchman Peak, 5 specimens (WAM 80.1333, 85.634); 0.8 km north-east of turn-off to Lucky Bay, Merivale 428219, 3 specimens (WAM 07.190); Lucky Bay, via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, Merivale 264386, 1 specimen (WAM 05.33); Ocumup No. 1 deep well, 68.6 m., Eucla Bay district. 2 specimens (WAM 95.406). Total 11 specimens.

DIMENSIONS

	Height	Width	No. of whorls
WAM 07.190a	11.5	4.1	7+ specimen broken

REMARKS

This species is very common in the late Eocene unnamed sandstone near Kalbarri, Western Australia. The specimens recorded here are all fragmentary and some somewhat worn, but nevertheless match closely the material from Kalbarri. No specimens have been found at the Thomson Road locality north of Walpole.

OCCURRENCE

Southern Carnarvon Basin: unnamed sandstone; **Eucla Basin**: Pallinup Formation.

Family Capulidae Fleming, 1822

Genus *Sirius* Hedley, 1900

Sirius sp.

Figures 1.12–13

MATERIAL EXAMINED

Australia: Western Australia: Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. 1 specimen (WAM 99.221). Total 1 specimen.

DESCRIPTION

Shell ovately fusiform of three or more tumid whorls. Protoconch broken, Teleoconch whorls rapidly increasing, last whorl ventricose, suture deeply incised. Sculpture of prominent beaded lirae, about 20 on last whorl, about nine on penultimate whorl. No obvious transverse sculpture (preservation poor?). Aperture subcircular, produced anteriorly into short canal. Inner lip with thin plate over columella, slightly reflexed over narrow umbilicus. Prominent fasciole separated from canal and aperture by deep furrow running into umbilicus.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 99.221	3.7	2.7	2.9	3+

REMARKS

The genus is known from species present in the late Eocene, Miocene and Recent of Australia, but this species doesn't resemble any of the fossil species. It is somewhat similar to the type species of the genus, *Sirius badius* (Tenison Woods, 1878), Recent, eastern and southern Australia but has more lirae.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Genus *Cerithioderma* Conrad, 1860

Cerithioderma tabulata (Tate, 1890)

Figures 1.14, 1.21

Trichotropis tabulata Tate, 1890: 187; Tate, 1892, plate 13, figure 4.

MATERIAL EXAMINED

Holotype

Australia: *South Australia*: SAM T766, Adelaide bore, Kent Town, South Australia.

Other material

Australia: *Western Australia*: Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. 2 specimens (WAM 69.171; NMV P329278). Total 2 specimens.

DESCRIPTION

Shell small, turbiniform, whorls four, convex with impressed sutures. Last whorl contracting abruptly to short canal. Axial sculpture of low, broad costae. Spiral sculpture of about six prominent lirae, beaded where crossed by costae. Base of shell sculptured with fine, close-set lirae. Aperture pyriform with short canal, outer lip internally lirate. Small umbilical chink.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
SAM T766, holotype	6.5	3.8		3+
WAM 69.171	5.5	3.6	2.2	4+

REMARKS

Of the Walpole material, one specimen is broken and worn, and the other is a worn juvenile (3 whorls) but sufficient morphology is preserved to show that they are identical with Tate's species from the Kent Town Bore (Figure 1.21).

OCCURRENCE

Eucla Basin: Pallinup Formation. **St Vincent Basin**: Blanche Point Formation (type). **Otway Basin**: Browns Creek Formation.

Family Cypraeidae Rafinesque, 1815

Genus *Zoila* Jousseaume, 1884

Zoila viathomsoni Darragh, 2011

Figures 3.33, 3.38–39

Zoila viathomsoni Darragh, 2011b: 5, Figures 1D, 2C, 5B–C, H, L.

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** WAM 72.296. Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486.

Paratypes

From type locality WAM 72.2539; NMV P310193–4.

Other material

WAM 82.1484, 15.277–8 from type locality. Total 14 specimens.

DESCRIPTION

Shell of average size for genus (19–28 mm in length), pyriform. Spire not visible on most specimens, projecting on one specimen. Posterior canal very short, slightly bent to left. Posterior canal very short, slightly deflected to right. Aperture slightly sinuous. Outer lip with about 23 to 25 teeth present along entire lip. Columella with about 23 to 26 teeth present along entire lip. Fossula well developed, deep, elongate, bounded anteriorly by thickened ridge; very weak notch present in inner edge just posterior to anterior ridge; weak terminal ridge joining edge of fossula. First columella tooth adjacent to terminal ridge, almost blocking shallow sulcus that descends into the fossula parallel to terminal ridge.

REMARKS

This is the oldest true cowry recorded from Australia. It has been discussed in detail by Darragh (2011b).

OCCURRENCE

Eucla Basin: Pallinup Formation.

Family Eocypraeidae Schilder, 1924

Genus *Willungia* Powell, 1938

Willungia ovulatella (Tate, 1890)

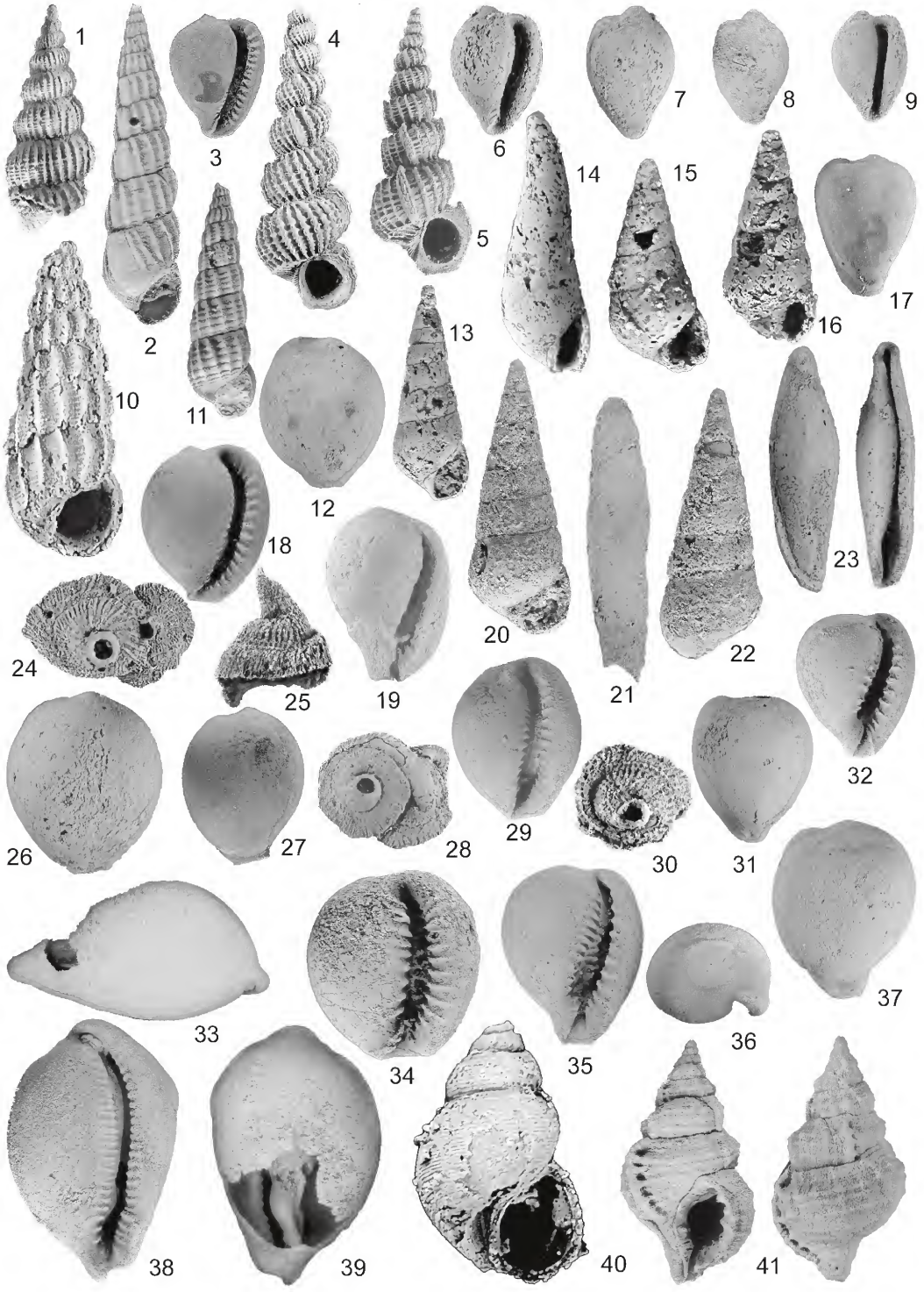
Figures 3. 19, 3.31–32, 3.35–37

Cypraea ovulatella Tate, 1890: 208; Tate 1892, plate 16, figures 7, 7a.

Austrocypraea ovulatella: Schilder, 1935: 339, Figure 18, non Tate, 1890.

Willungia ovulatella (Tate): Powell, 1938, plate 39, figure 5; Fehse, 2013: 150, Text-figure 4.

FIGURE 3 1, *Epitoniid* sp.: 1, WAM 10.04 (x 7);
2, 10, 11, *Notacirsa lampra* (Tate, 1890): 2, SAM T781B (x 5) holotype, Aldinga; 10, WAM 99.215 (x 10); 11, NMV P307865 (x 5), Blanche Point;
3, 6, 7, 8, 9, 17, *Archierato pyrulata* (Tate, 1890): 3, SAM T774B (x 4) lectotype, Adelaide bore; 6, 7, WAM 09.02b (x 5); 8, 9, WAM 09.02a (x 5); 17, SAM T774A (x 4) paralectotype, Adelaide bore;
4, 5, *Cirsotrema pleiophylla* Tate, 1890: 4, SAM 789K (x 4) lectotype, Torquay; 5, WAM 10.03 (x 4);
12, 18, 26, 27, 29, 34, *Triviella pompholugota* (Tate, 1890): 12, 29, WAM 07.09a (x 4); 18, 27, SAM T803 (x 4) holotype, Adelaide bore; 26, WAM 76.2542a (x 5); 34, WAM 76.2542b (x 5);
13, 20, 22, *Eulima danae* Tension Woods, 1879: 13, WAM 99.178b (x 4); 20, 22 WAM 99.178a (x 4);
14, *Melanella?* sp.: 14, WAM 15.70 (x 7);
15, *Curveulima?* sp.: 15, WAM 15.72 (x 10);
16, *Niso kimberi* Pritchard, 1906: 16, WAM 10.05 (x 7);
19, 31, 32, 35, 36, 37, *Willungia ovulatella* (Tate, 1890): 19, WAM 80.1342 (x 3) Cape Le Grand; 31, 32, WAM 09.06 (x 3); 35, 36, 37, WAM 76.2543a (x 3);
21, *Seraphs* sp.: WAM 84.1036 (x 1.5) Mount Barker;
23, *Phenacovolva* sp.: 22, 23, WAM 12.70 (x 3);
24, 25, 28, 30, *Thylacodes actinotus* Tate, 1893: 24, SAM T1521A (x 3) lectotype, Adelaide bore; 25, 30, WAM 15.299 (x 2); 28, SAM T 1521E (x 3) paralectotype, Adelaide bore.
33, 38, 39, *Zoila viathomsoni* Darragh, 2011: WAM 72.296 (x 3) holotype;
40, *Rissoid* sp.: 37, 99.216 (x 20);
41, *Sassia tortirostris* (Tate, 1888): 38, 39, WAM 72.299 (x 2).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MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. 227 specimens (WAM 67.135, 69.157, 72.242, 72.294, 76.2543, 82.1485, 99.179, 09.06, 10.15, 10.16; NMV P317176–80). Cape le Grand National Park, 0.8 km NE of turnoff to Lucky Bay, west side of road, Merivale 428219: 2 specimens (WAM 07.192). Cape Le Grand National Park, via Esperance, old track surface 3.7 km south-east from Frenchman Peak, 1 specimen (WAM 80.1342). Lucky Bay, via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, Merivale 264386, 2 specimens (WAM 04.185, 05.41). Total 232 specimens.

DESCRIPTION

Shell of small size for genus, globose, smooth, abruptly truncated anteriorly to anterior canal. Spire barely, if at all, projecting. Aperture arcuate, narrow posteriorly, widening anteriorly and then abruptly narrowing to anterior canal. Posterior canal indistinct, barely notched. Anterior canal short, prominent, bounded by ridges on columella and labial sides, almost closed. Terminal ridge bifid. Labial lip with 10–12 teeth. Inner lip with 10–12 elongate ridges extending well into aperture. Shallow subcircular fossula, crossed by very weak ribs that become stronger after crossing fossula. Wide shallow groove between terminal ridge and first columella rib.

DIMENSIONS

	Height	Width
WAM 09.06	9.4	7.6
WAM 76.2543a	11.3	8.8
WAM 80.1342	10.7	7.6

REMARKS

Walpole specimens are identical in shape to those from Browns Creek but they are consistently smaller. Both have similar teeth and outer lip. Browns Creek specimens are generally much bigger than those from Blanche Point and Blanche Point specimens are generally slightly bigger than Walpole specimens. Most of the Blanche Point specimens are crushed. This species has a paucispiral protoconch suggesting that the species had direct developing larvae. The genus ranges late Eocene-early Miocene in Australia and late Oligocene-middle Miocene in New Zealand. The large number of specimens present suggests this species might have been a spongophore.

OCCURRENCE

Eucla Basin, Pallinup Formation. **St Vincent Basin**: Blanche Point Formation (type). **Otway Basin**: Browns Creek Formation.

Family Ovulidae Fleming, 1822

Genus *Phenacovolva* Iredale, 1930

Phenacovolva sp.

Figures 3.23

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 12.70. Total 1 specimen.

DESCRIPTION

Shell of average size for genus, elongate fusiform, smooth. Aperture very narrow, slightly wider anteriorly. Four weak denticles present at anterior end of columella.

DIMENSIONS

	Height	Width
WAM 12.70	15.0	4.4

REMARKS

The single specimen is slightly crushed dorso-ventrally. This is the earliest record of the genus in Australia and the only record for the genus in the Australian Eocene. The only other species of the genus known in the Australian fossil record is *Phenacovolva exigua* (Tate, 1890) from the middle Miocene of Victoria.

OCCURRENCE

Eucla Basin, Pallinup Formation.

Family Naticidae Guilding, 1834

Genus *Tanea* Marwick, 1931

Tanea hamiltonensis (Tenison Woods, 1879)

Figures 1.6, 1.9, 1.10–11

Natica wintlei var. hamiltonensis Tenison Woods, 1879a: 229, plate 21, figure 8.

Natica hamiltonensis Tenison Woods: Tate, 1893: 319, plate 10, figure 6.

Tanea hamiltonensis (Tenison Woods): Ludbrook, 1958: 48, plate. 1, figures 9–10.

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: 285 specimens (WAM 67.133, 69.156, 72.244, 72.297, 82.1486, 99.181, 04.158, 10.27–29, 12.01–03; NMV P317493–6). Lucky Bay via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, Merivale 264386: 1 specimen (WAM 05.39?). Total 286 specimens.

DESCRIPTION

Shell smooth, solid, globose, of small size (3.8–6 mm) with low spire. Protoconch smooth, of about one whorl coiled in axis of shell and merging imperceptibly with teleoconch whorls. No spiral sculpture. Axial sculpture of fine growth striae only. Aperture D shaped. Umbilicus open, deep, narrow with a very fine funicle running up umbilicus.

DIMENSIONS

	Height	Width	No. of whorls
WAM 12.01	4.8	5.2	3
WAM 12.02	5.0	5.7	3
WAM 12.04	2.8	2.1	

REMARKS

This is one of the most common species in the Pallinup Formation. It has a long time range (late Eocene to middle Miocene) and a wide distribution. The Eocene specimens from the Pallinup Formation, Blanche Point Formation and Browns Creek Formation are much smaller than the average size of the Miocene specimens and the funicle is generally much less prominent. It is possible that many of the specimens are juveniles.

This seems to be the only naticid species present in the Pallinup Formation, so the two opercula found at Walpole (Figures 1.10–11) probably belong to this species. It is probably responsible for the naticid boreholes present in other molluscs in the formation.

OCCURRENCE

Eucla Basin: Pallinup Formation. **St Vincent Basin**: Blanche Point Formation **Otway Basin**: Browns Creek Formation; Jan Juc Formation, Muddy Creek Formation, Gellibrand Formation, Fyansford Formation.

Family Ampullinidae Cossmann, 1918

Genus *Euspirocrommium* Sacco, 1890

Euspirocrommium? sp.

Figures 1.7–8, 1.18

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Grid reference Deep River 743 486: WAM 99.208, 12.05, NMV P317498–9. Total 4 specimens.

DESCRIPTION

Shell solid, globose, of average size for genus (23 mm). Protoconch worn and indistinct. Spire somewhat gradate with about five regularly rounded whorls; sutures impressed. Aperture not preserved. Small umbilicus present.

DIMENSIONS

	Height	Width	No. of whorls
WAM 99.208	8.5		5+
WAM 12.05	23.4	14	5

REMARKS

All specimens are incomplete. Specimen WAM 12.05 shows indications of tearing by a crab. *Euspirocrommium effusum* (Tate, 1893) has a narrower and more gradate spire. The specimen of *Euspirocrommium* recorded from the late Eocene of Kalbarri by Darragh and Kendrick (2008) has a much more gradate spire than this species.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Family Rissoidae Gray, 1847

Genus and species indeterminate

Figure 3.40

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Grid reference Deep River 743 486: 1 specimen (WAM 99.216).

DESCRIPTION

Shell turbiniform, of very small size. Protoconch broken. About 3½ regularly convex whorls. No axial sculpture. Spiral sculpture of fine, closely spaced threads over whole whorl. Aperture lenticular with weak posterior notch. Narrow umbilicus present.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 99.216	2.5	1.6	0.9	3½

REMARKS

The single specimen is poorly preserved. Not only is the protoconch missing, but the dorsal side of the teleoconch has large holes in each whorl and the aperture is damaged, so assignment to genus or family is not possible. It bears some resemblance to species of the rissoid genera *Onoba* H. & A. Adams, 1852 or *Lucidestea* Laseron, 1956.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Family Seraphsidae Gray, 1853

Genus *Seraphs* Montfort, 1810

Seraphs sp.

Figure 3.21

MATERIAL EXAMINED

Australia: ***Western Australia*:** Mt Barker, Plantagenet Location 6129, Mount Barker Rd. 8 specimens (WAM 84.1021–2, 84.1034–9).

DIMENSIONS

	Height
WAM 84.1036	34.5

REMARKS

The eight specimens are casts and moulds but sufficiently well preserved to enable generic assignment but too poorly preserved to formally name. The genus ranges from Paleocene to Oligocene and has a Tethyan distribution. It has not been recorded from Australia previously. The nearest occurrence is in the Eocene of Java.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Family Ranellidae Gray, 1853

Genus *Sassia* Bellardi, 1872

Sassia tortirostris (Tate, 1888)

Figures 3.41

Triton tortirostris Tate, 1888: 123, plate 5, figure 7.

Triton oligostirus Tate, 1888: 126, plate 6, figure 7.

Cymatiella oligostirus (Tate): Ludbrook, 1973: plate 25, figure 29.

Sassia tortirostris (Tate): Beu and Maxwell, 1990: 223 (with synonymy).

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Grid reference Deep River 743 486: WAM 67.137, 69.160, 69.170, 99.182, 72.299, 04.160, 09.29, 10.08, 10.09; NMV P316328, P316329, P316330, P317781, P332655. Total 69 specimens.

DESCRIPTION

Shell of small size for genus, up to 23 mm. Protoconch dome-shaped, of 2½ smooth whorls, coiled with axis of shell. Teleoconch of 5–7 convex whorls with impressed sutures. Spiral sculpture of six irregularly spaced prominent lirae with one to three finer lirae in interspaces, total of 24 lirae on last whorl extending onto siphonal canal. Axial sculpture of 12 costae forming prominent tubercles where crossed by spiral lirae; varices at every ⅔ of a whorl. Last whorl contracting evenly to siphonal canal. Aperture ovate, outer lip with six prominent internal denticles; columella with one prominent posterior denticle and two to three prominent anterior denticles; siphonal canal short.

DIMENSIONS

	Height	Width	No. of whorls
WAM 72.299	22.8	13.0	7 protoconch broken

REMARKS

Walpole specimens closely resemble specimens from Eocene formations of the St Vincent and Otway basins, which were previously identified as *Sassia oligostira*. Most of the Walpole specimens are small juveniles. Specimens from the Eocene formations are smaller than specimens from Oligocene and Miocene formations. Miocene specimens of *S. tortirostris* can exceed 60 mm in length.

OCCURRENCE

Eucla Basin: Pallinup Formation. **St Vincent Basin**: Blanche Point Formation (type). **Otway Basin**: Browns Creek Formation; Glen Aire Clay; Jan Juc Formation; Gellibrand Formation, Fyansford Formation. Late Eocene-Middle Miocene.

Family Triviidae Troschel, 1863

Genus *Triviellia* Jousseaume, 1884

Triviella pompholugota (Tate, 1890)

Figures 3.12, 3.18, 3.26–27, 3.29, 3.34

Trivia pompholugota Tate, 1890: 214.

Triviella pompholugota (Tate). Fehse and Grego, 2004: 7, plate 27, figure 110.

MATERIAL EXAMINED

Holotype

Australia: ***South Australia*:** SAM T803, Adelaide (= Kent Town) Bore.

Other material

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. 501 specimens (WAM 67.136, 69.158, 72.243, 72.295, 76.2542, 76.2544, 76.2545, 79.1020, 99.180, 09.07, 10.20–22; NMV P316001–5, P317186). Cape Le Grand National Park, via Esperance, old track surface 3.7 km south-east from Frenchman Peak, 1 specimen (WAM 80.1343). Total 502 specimens.

DESCRIPTION

Shell globular, smooth, of medium to small size for genus (5.5–8 mm). Spire scarcely projecting. Aperture narrow, uniformly curved; outer lip thickened, with short, thick-sided anal notch, labial teeth 13–16, columella teeth 11–13. Anterior canal very short, notched with thickened sides. Fossula broad, concave, bisected by sharp ridge, extremely fine terminal ridge; in some specimens columella teeth extend as ridges across fossula.

DIMENSIONS

	Height	Width	Labial teeth	Columella teeth
SAM T803, holotype	7.3	5.6		
WAM 09.07a	6.9	5.9	12	15
WAM 76.2542a	7.1	6.0	13	11
WAM 76.2542b	7.2	6.8	12	12

REMARKS

Most Walpole specimens are about half the size of most Browns Creek specimens, but small specimens from Browns Creek are very similar to the Walpole specimens. One specimen from Aldinga is the same as the largest Walpole specimens. The holotype of the species from Kent Town Bore (Figures 3.18, 3.27) is about the same size as Walpole specimens. This species differs from most others in the genus by the complete lack of any ribbing on the lateral and dorsal surfaces.

OCCURRENCE

Eucla Basin: Pallinup Formation. **St Vincent Basin**: Blanche Point Formation (type) **Otway Basin**: Browns Creek Formation.

Genus *Archierato* Schilder, 1933

Archierato pyrulata (Tate, 1890)

Figures 3.3, 3.6–9, 3.17

Erato pyrulata Tate, 1890: p. 216. Tate, 1892: plate 13, figures 12, 12a.

Archierato pyrulata Tate. Schilder, 1933: 253, 257, 270, Figure 8. Schilder, 1935: 328, Figure 1.

MATERIAL EXAMINED

Types

Australia: ***South Australia*:** SAM T774A–F from Blanche Point Marl, Adelaide (= Kent Town) Bore. Tate's figured specimen (T774B) is chosen as lectotype to fix the status of the specimen as the sole name-bearing type of the species.

Paralectotypes

SAM T774B–F from the same locality.

Other material

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. 177 specimens (WAM 67.164, 69.183, 72.249, 72.316, 99.177, 04.159, 04.173, 09.02, 10.23–5; NMV P317189, P317490–2). Cape Le Grand National Park, via Esperance, old track surface 3.7 km south-east from Frenchman Peak, 1 specimen (WAM 80.1353). Lucky Bay, via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, Merivale 264386, 1 specimen (WAM, 05.40). Total 179 specimens.

DESCRIPTION

Shell small, of average size for genus (4–5.4 mm), smooth, pyriform, with slightly projecting spire. Protoconch of about 1 to 1½ smooth whorls passing imperceptibly into teleoconch whorls. Teleoconch of about three whorls. Aperture long and narrow, slightly sinuous; outer lip prominently thickened with traces of up to 13 week teeth. Columella with two to six teeth. Terminal ridge prominent, bounding shallow subrectangular fossula with sharp internal edge.

DIMENSIONS

	Height	Width
WAM 09.02a	4.1	2.9
WAM 09.02b	4.9	3.4

REMARKS

Walpole specimens are very similar in morphology to the specimens from the Blanche Point Formation in South Australia, but the apertural teeth tend to be much weaker like specimens from the Browns Creek Formation in Victoria.

OCCURRENCE

Eucla Basin: Pallinup Formation. **St Vincent Basin**: Blanche Point Formation (type). **Otway Basin**: Browns Creek Formation.

Family Vermetidae Rafinesque, 1815

Genus *Thylacodes* Guettard, 1770

Thylacodes actinotus Tate, 1893

Figures 3.24–25, 3.28, 3.30

Thylacodes actinotus Tate, 1893: 342, plate 9, figure 1.

MATERIAL EXAMINED

Types

Australia: ***South Australia*:** SAM T1521A–E from Blanche Point Marl, Adelaide (= Kent Town) Bore. Tate's figured specimen (T1521A) is chosen as lectotype to fix the status of the specimen as the sole name-bearing type of the species.

Paralectotypes

SAM T1521B–E from the same locality.

Other material

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. 1 specimen (WAM 15.299). Total 1 specimen.

DESCRIPTION

Shell small, irregularly conical, early whorls somewhat flattened, embracing except for last whorl which is extended into a short erect circular tube. Sculptured with axial costae crossed by weak longitudinal threads.

DIMENSIONS

	Height	Width
WAM 15.299	12.6	10.9

REMARKS

Dr R. Bieler (personal communication), having examined images of the Thomson Road specimen and Tate's types, confirmed that the species was a vermetid as was assumed in Bieler and Petit (2011). The attachment surface of the Thomson Road specimen is dimpled indicating possible attachment to a sponge.

OCCURRENCE

Eucla Basin: Pallinup Formation. **St Vincent Basin**: Blanche Point Formation (type).

Family Xenophoridae Troschel, 1852 (1840)

Genus *Xenophora* Fischer von Waldheim, 1807

Xenophora sp.

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Grid reference Deep River 743 486: (WAM 67.180).

REMARKS

Ponder (1983, p. 29) regarded the single broken specimen as a typical member of the *Xenophora conchliophora* group. Since his examination of it, the specimen has been lost. A similar if not identical species from the late Eocene, unnamed sandstone near Kalbarri was recorded by Darragh and Kendrick (2008, p. 233, Figures 2.12–13) as *Xenophora* sp, cf. *X. tatei* Harris, 1897. These two records are the only records of the genus known from the Australian Eocene as no species have been found from the late Eocene of eastern Australia. The earliest record in eastern Australia is from the late Oligocene of the Otway Basin.

Family Epitoniidae Berry, 1910 (1812)

Genus *Notacirsa* Finlay, 1926

Notacirsa lampra (Tate, 1890)

Figures 3.2, 3.10–11

Scalaria (Hemiacirsa) lampra Tate, 1890: 234; Tate 1892: plate 11, figure 8.

MATERIAL EXAMINED

Types

Australia: ***South Australia*:** Aldinga. (SAM T781 A–G). Tate's figured specimen (T781B) is chosen as lectotype to fix the status of the specimen as the sole name-bearing type of the species.

Other material

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: (WAM 67.131, 99.215). Total 2 specimens.

***South Australia*:** Aldinga, lower part of cliff, Blanche Point. (P307865). 2 specimens.

DESCRIPTION

Spire elongate turriteliform; teleoconch whorls flat with sharp axial costae running from suture to suture, almost aligned from whorl to whorl, 14 present on penultimate whorl; spiral sculpture of fine, evenly spaced lirae, 11 on penultimate whorl. Last whorl with about 15 weak spiral lirae, axial costae not sharp and slightly weaker, with low broad varix at aperture. Aperture oval. Columella concave. No callus.

DIMENSIONS

	Height	Width	No. of whorls
SAM T781B, lectotype	11.7	3.0	10
WAM 99.215	5.8	2.1	7+ juvenile whorls missing
NMV P307865	9.5	2.7	8+ juvenile whorls missing

REMARKS

The two Walpole specimens are similar to specimens of *Notacirsa lampra* Tate from the St Vincent and Otway Basins, but the costae are slightly sharper than most of the latter specimens, but fall within the range of variation. Mature specimens of the species can reach up to 14 mm in length.

OCCURRENCE

Eucla Basin: Pallinup Formation. **St Vincent Basin**: Blanche Point Formation (type). **Otway Basin**: Browns Creek Formation; Glen Aire Clay.

Genus *Cirsotrema* Mörch 1852

Cirsotrema pleiophylla Tate, 1890

Figures 3.4–5

Scalaria (Cirsotrema) pleiophylla Tate, 1890: 231; 1892: plate 12, figure 1.

MATERIAL EXAMINED

Types

Australia: ***Victoria*:** Spring Creek (= Torquay). (SAM T789 A–K). Tate's figured specimen (T789K) is chosen as lectotype to fix the status of the specimen as the sole name-bearing type of the species.

Other material

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: WAM 67.130, 69.155, 04.155–6, 10.02–3; 15.272–4; NMV P316319–21. Total 31 fragmentary specimens

DESCRIPTION

Shell of average size for genus, turrited of 7–8 strongly convex teleoconch whorls (apical whorls missing on all specimens). Sutures impressed. Axial sculpture of 17–24 equidistant, frilled lamellae, slightly produced into a point posteriorly, thick foliaceous varices present at about 180° on some specimens, at irregular intervals on others; varices produced into a point posteriorly. Spiral sculpture of 11–12 lirae about as wide as interspaces, weakly developed against posterior suture. Prominent peripheral rib present on last whorl coinciding with posterior suture. Aperture subcircular, apertural lip entire.

DIMENSIONS

	Height	Width	No. of whorls
SAM T789K, lectotype	14.0	4.7	7+ broken
WAM 10.03	12.2	4.5	8

REMARKS

This species has the same basic form as the southern Australian Eocene species *Cirsotrema mariae* (Tate, 1885) but is much smaller and more delicate, having finer axial and spiral sculpture. A somewhat similar species occurs in Eocene sandstones at Kalbarri National Park (Darragh and Kendrick, 2008).

OCCURRENCE

Eucla Basin: Pallinup Formation. **St Vincent Basin**: Blanche Point Formation. **Otway Basin**: Browns Creek Formation, Jan Juc Formation (type).

Epitoniid sp.

Figure 3.1

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, west side, Deep River 743 486: WAM 10.04. Total specimens 1.

DESCRIPTION

Shell of small size; with protoconch of about two whorls, the first whorl deviated at about a right angle to shell axis; spire elongate turriteliform; sutures moderately incised; teleoconch whorls convex with sharp, regularly spaced axial costae running from suture to suture, about 26 present on last preserved whorl, much narrower than interspaces; spiral sculpture of fine, evenly spaced lirae, thinner than interspaces, about 12 on last preserved whorl. Aperture not preserved.

DIMENSIONS

	Height	Width	No. of whorls
WAM 10.04	6.9	3.0 (max)	9+ broken and squashed laterally

REMARKS

There is nothing in the St Vincents and Otway Basins matching this taxon, but preservation may be deceiving.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Family Eulimidae Philippi, 1853

Eulimid species are parasitic on a variety of echinoderms. McNamara (1985) recorded *Linthia, Schizaster, Prenaster, Giraliaster* and *?Pericosmus* in the Pallinup Formation at Walpole and spines of regular echinoids have been found at Walpole, but given that there are four generic taxa recorded here, it may be that other yet unrecognised echinodermata such as holothurians, whose remains, if preserved, would be difficult to recover, were also present in the formation.

Genus *Eulima* Risso, 1826

Eulima danae Tenison Woods, 1879

Figures 3.13, 3.20, 3.22

Eulima danae Tenison Woods, 1879b:2, plate 1, figure 1.

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: 43 specimens (WAM 67.123,

99.178; 04.178, 15.269–271; NMV P316323, P316324–7). Lucky Bay via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, Merivale 264386. 3 specimens (WAM 04.184, 05.44). Cape Le Grand National Park, old track surface, 3.7 km south-east of Frenchman Peak. (WAM 80.1341, 85.636). Total 49 specimens.

DESCRIPTION

Shell of average size for genus; elongate, slender; teleoconch whorls 9–11, smooth except for very fine growth striae and incremental scars. Early whorls flat, then tending to slightly convex on last whorls of large specimens. Protoconch of about 1½ smooth, shining whorls, the first whorl slightly deviated from shell axis. Aperture elliptical with opisthocline outer lip.

DIMENSIONS

	Height	Width	No. of whorls
WAM 99.178a	12.4	4.5	9+ juvenile whorls broken off
WAM 99.178b	9.8	3.3	9

REMARKS

The Walpole and Cape Le Grand specimens are very similar in morphology to specimens of the same size from Muddy Creek. Browns Creek specimens of this species can reach up to 25 mm in length and consist of 15 whorls and are much the same size as large specimens from Muddy Creek (type locality).

OCCURRENCE

Eucla Basin: Pallinup Formation. **St Vincent Basin**: Blanche Point Formation. **Otway Basin**: Browns Creek Formation, Glen Aire Clay, Jan Juc Formation; Gellibrand Formation, Muddy Creek Marl (type), Fyansford Formation. Late Eocene–Middle Miocene.

Genus *Niso* Risso, 1826

Niso kimberi Pritchard, 1906

Figure 3.16

Niso kimberi Pritchard, 1906:119.

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: WAM 10.05; NMV P316322. Total 2 specimens.

DESCRIPTION

Shell of average size for genus; spire elongate with flat, shining, smooth teleoconch whorls. Last whorl contracting abruptly to base. Aperture narrow, lenticular. Umbilicus prominent, coniform with sharp margin.

DIMENSIONS

	Height	Width	No. of whorls
WAM 10.05	5.7	2.5	8+ juvenile whorls broken off

REMARKS

The two specimens are similar to specimens of *Niso kimberi* from the Otway Basin, but no specimens from the Blanche Point Formation, St Vincent Basin, are available for comparison, as it seems to be very rare in it. The species is very close in morphology to the Victorian Miocene species *Niso psila* Tenison Woods, 1879, but differs, as Pritchard correctly noted, by its flatter whorls, narrower spire and narrower umbilicus.

OCCURRENCE

Eucla Basin: Pallinup Formation. **St Vincent Basin**: Blanche Point Formation (type). **Otway Basin**: Browns Creek Formation.

Genus *Curveulima* Laseron, 1955

Curveulima? sp.

Figure 3.15

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: WAM 15.72–3, NMV P329300. Total 5 specimens.

DESCRIPTION

Shell of average size for genus; spire somewhat conical, slightly curved, with 6–7 flat, shining, slightly convex smooth whorls. Protoconch of about one smooth, rounded whorl, deviated from axis of shell. Subsutural band present on all whorls. No incremental scars present. Aperture broadly elliptical; outer lip with broad, shallow sinus.

DIMENSIONS

	Height	Width	No. of whorls
WAM 15.72	3.9	1.6	6

REMARKS

Apart from the next taxon, nothing similar has yet been recorded from the Tertiary of Australia, though there are many living species of the genus and similar genera known from Australia.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Genus *Melanella* Bowdich, 1822

Melanella? sp.

Figure 3.14

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: WAM 69.195, 15.69–71; NMV P329297–9. Total 14 specimens.

DESCRIPTION

Shell of average size for genus; spire very elongate, slightly sinuous, with 7–8 flat, shining, smooth whorls. Subsutural band present on all whorls. No incremental scars present. Aperture narrow, lenticular; outer lip sinuous with sinus against posterior suture, protruding slightly at middle of lip.

DIMENSIONS

	Height	Width	No. of whorls
WAM 15.70	6.8	2.1	7

REMARKS

Owing to the lack of preservation of the protoconch, the generic assignment of this species is doubtful. Apart from the previous taxon, nothing similar has yet been recorded from the Tertiary of Australia, though there are many living species of the genus and similar genera known from Australia.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Family Triphoridae Gray, 1847

Genus *Viriola* Jousseaume, 1884

Viriola? sp.

Figure 4.34

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: WAM 15.85–6, NMV P329310. Total 6 specimens.

DESCRIPTION

Shell sinistral, turriculate, of average size for genus (11–15 mm); whorls convex with impressed sutures. Protoconch poorly preserved (multipiral?). Spiral sculpture of strong lirae slightly narrower than interspaces, 7–8 lirae on penultimate whorl, 10-11 lirae on last whorl from suture to canal. No axial sculpture except for growth striae. Aperture oval with very short, twisted canal. No siphonal fasciole.

DIMENSIONS

	Height	Width	No. of whorls
WAM 15.85	11.7	2.7	10+ specimen broken

REMARKS

All specimens are not well preserved. The generic assignment is tentative. This species differs from most species of *Viriola* in having slightly convex rather than flat whorls.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Genus *Mastoniaeforis* Jousseaume, 1884

Mastoniaeforis pagodiformis sp. nov.

Figures 4.14–18

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MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 69.153a.

Paratypes

WAM 15.25 from type locality. NMV P327573 from type locality.

Other material

From type locality: 18 specimens (15.24, 15.26; NMV P327572, P327574). Ocumup No. 1 deep well, 53.4 m., Eucla Bay district. 1 specimen (WAM 95.433). Total 22 specimens.

DIAGNOSIS

Shell with four nodulate lirae, anterior lira developed into prominent keel.

DESCRIPTION

Shell very slender, elongate-conical, of about 8-10 keeled whorls with impressed sutures. Protoconch of about two whorls merging gradually with teleoconch, first whorl smooth, last whorl with prominent keel. Spiral sculpture of four lirae, narrower than interspaces, one against anterior suture, another against posterior suture, central two slighter thicker, the anterior of which is larger and forms prominent keel. Axial sculpture of low costae produced into prominent elongate nodes on crossing lirae to form a cancellate sculptural pattern. Aperture subcircular, entire, produced into short tube. Posterior canal produced into a short tube, projecting on dorsal side 180° from aperture. Anterior canal enclosed, produced into a short tube directed dorsally.

DIMENSIONS

	Height	Width	No. of whorls
WAM 69.153a, holotype	4.7	1.1	8+
WAM 15.25, paratype	4.9	1.1	9
NMV P327573, paratype	5.4	1.6	6+

ETYMOLOGY

Latin adjective. Shaped like a pagoda.

REMARKS

This species resembles *Mastoniaeforis insulana* (Laseron, 1958) from Christmas Island, but has a much more prominent keel. The protoconch seems to lack any axial sculpture unlike the protoconch of *Mastoniaeforis* illustrated by Marshall (1983, Fig 20E–F). Nothing like this species has yet been recorded from the Tertiary formations elsewhere in Australia.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Genus *Inella* Bayle, 1879

Inella moniliferata sp. nov.

Figures 4.1–3

urn:lsid:zoobank.org:act:68C91E29-AF80-4BF9-9E73-3CE1CD908110

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 15.29.

Paratypes

WAM 99.169a from type locality. NMV P327577 from type locality.

Other material

From type locality: 137 specimens (WAM 67.113–4, 67.128–9, 69.151a, 72.289, 99. 168, 04.152a, 04. 154, 15.27–8, 15.30; NMV P302233, P327575–6, P327578). Ocumup No. 1 deep well, 53.4 m, Eucla Bay district. 2 specimens (WAM 95.385, 95.434). Total 142 specimens.

DIAGNOSIS

Shell with three prominent nodulate lirae and one thin smooth lira against anterior suture of whorls.

DESCRIPTION

Shell sinistral, narrowly conical, of average size for genus (7–19 mm) with about 10–12 flat whorls. Protoconch of about 4½ whorls bearing three sharp lirae about as wide as interspaces merging imperceptibly into teleoconch whorls. Spiral sculpture of three lirae about as wide as interspaces with prominent nodules where crossed by axial sculpture. Thinner, smooth anterior lira against anterior suture. Axial sculpture of very weak oblique costae, only visible on crossing lirae. Base of shell smooth or with two or three smooth lirae. Aperture subrectangular. Columella covered with thick layer of callus. Very short twisted anterior canal.

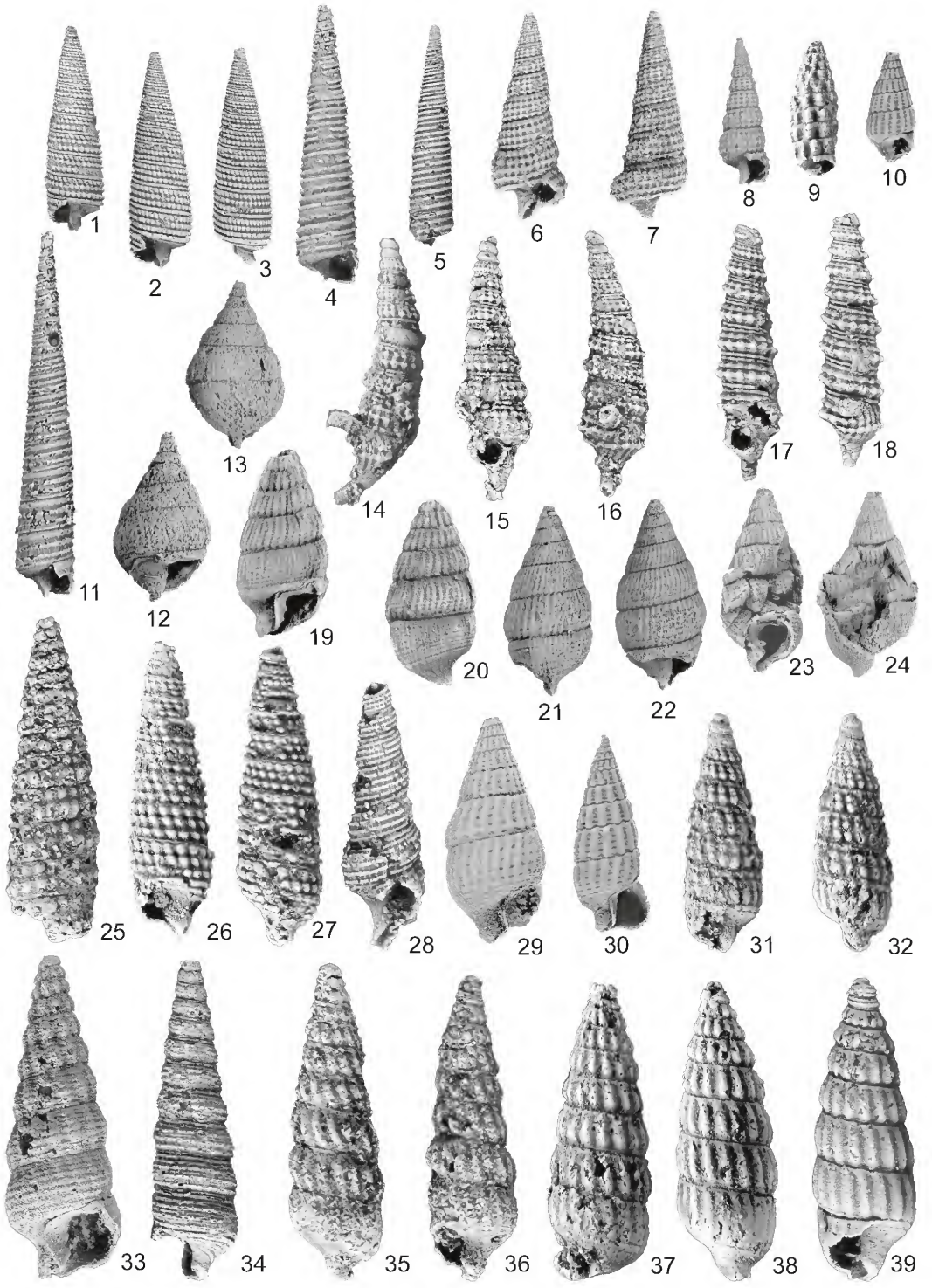
DIMENSIONS

	Height	Width	No. of whorls
WAM 15.29, holotype	10.0	2.8	11
WAM 99.169a, paratype	9.3	2.6	11
NMV P327577, paratype	8.4	2.4	10

ETYMOLOGY

Latin adjective. Monile a necklace; -ferata having.

FIGURE 4 1, 2, 3, *Inella moniliferata* sp. nov.: WAM 99.169a (x 4) paratype; 2, 3, WAM 15.29 (x 4) holotype;
4, 5, 11, *Seila stenopyrgisca* sp. nov.: 4, WAM 15.21 (x 5) paratype; 5, WAM 15.20 (x 5) paratype; 11 WAM 15.19 (x 5) holotype;
6, 7, 8, *Cerithiopsis pustuloclathrata* sp. nov.: 6, 7, WAM 69.136 (x 3) holotype; 8, WAM 72.291a (x 3) paratype;
9, Cerithiopsid sp.: 9, WAM 15.268 (x 5);
10, 29, 30 *Ataxocerithium concatenatum* Tate, 1893: 10, SAM T241F (x 5), lectoparatype, Adelaide bore; 29, SAM T241A (x 4) lectotype, Adelaide bore; 30, SAM T241E (x 5) lectoparatype, Adelaide bore;
12, 13, 19, 20, 21, 22, 23, 24, *Ataxocerithium otopleuroides* sp. nov.: 12, 13, WAM 12.60 (x 3) holotype; 19, 20, WAM 80.1335a (x 3) paratype; 21, 22, WAM 05.57a (x 3) paratype; 23, 24, WAM 05.52 (x 2) paratype;
14, 15, 16, 17, 18, *Mastoniaeforis pagodiformis* sp. nov.: 14, 15, 16, WAM 15.25 (x 10) paratype; 17, 18, WAM 69.153a (x 10) holotype;
25, 26, 27, 31, 32, *Inella dauciformis* sp. nov.: 25, WAM 15.57 (x 10) paratype; 26, 27, WAM 15.58 (x 10) holotype; 31, 32, WAM 15.59 (x 10) paratype;
28, Cerithiopsid sp.: 28, WAM 15.287 (x 10);
33, *Eocolina* sp.: 33, WAM 82.1483 (x 4);
34, *Viriola* sp.: 34, WAM 15.85 (x 5);
35, 36, 37, 38, 39, *Costatophora? pulcherrima* sp. nov.: 35, 36, WAM 15.66 (x 10) paratype; 37, WAM 15.64 (x 10) paratype ; 38, 39 WAM 15.62 (x 10) holotype.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REMARKS

This species has some resemblance to *Inella aoteaensis* (Marshall and Murdoch, 1920) from the middle Eocene of New Zealand, but has an extra beaded lira. Its sculpture resembles *I. carinata* Marsall, 1983, Recent, South Australia, but it has a prominent smooth anterior lira not present on the latter.

OCCURRENCE

Eucla Basin: Pallinup Formation.

***Inella dauciformis* sp. nov.**

Figures 4.25–27, 4.31–32

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MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 15.58.

Paratypes

WAM 15.57, 15.59 from type locality. NMV P329290 from type locality.

Other material

From type locality: 15 specimens (WAM 15.60–61; 04.152b?, NMV P329291–2). Ocumup No. 1 deep well, 53.4 m, Eucla Bay district. 1 specimen (WAM 95.384). Total specimens 16.

DIAGNOSIS

Shell with three broad, coarsely nodulate lirae, crossed by prosocline grooves.

DESCRIPTION

Shell sinistral, narrowly cyrtoconical of small size for genus (4.5–6.2 mm). Protoconch of 2½ whorls, with three sharp lirae, merging abruptly into teleoconch whorls. Spiral sculpture of three broad lirae, much wider than interspaces and broken into prominent nodules by prosocline grooves; posterior lira weaker than anterior pair on some specimens. Aperture ovate, weakly notched posteriorly and produced into a very short, twisted anterior canal.

DIMENSIONS

	Height	Width	No. of whorls
WAM 15.58, holotype	5.5	1.5	9
WAM 15.57, paratype	6.0	1.7	10+ specimen broken
WAM 15.59, paratype	4.4	1.5	7
NMV P329290, paratype	4.4	1.4	8

ETYMOLOGY

Latin adjective. Dauciformis shaped like a carrot.

REMARKS

Compared with *Inella moniliferata* sp. nov. this species is smaller, relatively narrower and has consistently coarser sculpture with more prominent nodules on the lirae. It also lacks the smooth anterior lira present on that species. The protoconch is similarly sculptured but has one whorl less than that of *I. moniliferata.*

OCCURRENCE

Eucla Basin: Pallinup Formation.

Genus *Costatophora* B. A. Marshall, 1994

***Costatophora pulcherrima* sp. nov.**

Figures 4.35–39

urn:lsid:zoobank.org:act:D8B52DA8-D7F8-4492-BE13-7F5478FBA6B7

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 15.62.

Paratypes

WAM 15.64, 15.66 from type locality. NMV P329294 from type locality.

Other material

From type locality: WAM 67.134, 15.63, 69.151b, 15.65; NMV P329293, P329295. Total specimens 24.

DIAGNOSIS

Shell cyrtoconical with broad costae extending from suture to suture and with one thin lira adjacent to anterior suture.

DESCRIPTION

Shell sinistral, narrowly cyrtoconical, of average size for genus, of 6–8 slightly convex whorls, last whorl roundly truncated to anterior canal. Protoconch of three whorls bearing three spiral lirae merging abruptly into teleoconch, posterior lira beaded. Axial sculpture of broad costae extending from suture to suture, slightly narrower than interspaces, about 19 on penultimate whorl, 19–21 on last whorl becoming weaker aperturally, slightly nodulate on first two whorls. Spiral sculpture of one thin lira adjacent to anterior suture. On last whorl two spiral grooves against the posterior suture. Aperture elongate lenticular with short anterior canal.

DIMENSIONS

	Height	Width	No. of whorls
WAM 15.62, holotype	5.5	1.7	6
WAM 15.64, paratype	5.4	1.9	7
WAM 15.66, paratype	5.6	1.6	8
NMV P329294, paratype	5.3	1.7	6

ETYMOLOGY

Latin adjective. Pulcherrima most beautiful.

REMARKS

No specimen has a complete aperture, so apertural details are not known. This species is unusual in that it lacks almost all spiral sculpture. The lirate protoconch is similar to the species of *Inella* recorded from here and to species illustrated by Marshall (1983), whereas it has some resemblance to *Costatophora serana* (P.J. Fischer, 1927), Pliocene and Recent, Indonesia, but the protoconch of that species has prominent axial sculpture quite unlike that of this species and the costae are not so prominent. It may represent a new genus, but given the quality of preservation, it seems unwise to erect a new taxon.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Family Cerithiopsidae H. & A. Adams, 1853

Genus *Seila* A. Adams, 1861

Seila stenopyrgisca sp. nov.

Figures 4.4–5, 4.11

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MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 15.19.

Paratypes

WAM 15.20–1 from type locality. NMV P332349 from type locality.

Other material

From type locality: 186 specimens (WAM 67.125, 69.133, 69.140, 69.150, 99.170, 99.172, 04.151, 15.15–18; NMV P302247-8, P302250, P302299, P327567). Cape Le Grand National Park, old track surface, 3.7 km south-east of Frenchman Peak 2 specimens (WAM 85.635, 85.1450). Total 191.

DIAGNOSIS

Shell aciculate with three prominent rounded cords, weakly beaded where crossed by fine axial threads.

DESCRIPTION

Shell narrowly conical, very elongate, of about 15–17 flat whorls, of average size for genus (10–13.6 mm), contracting abruptly to base. Protoconch of 2–3½ whorls, axially costate and merging abruptly with teleoconch. Axial sculpture of very fine, close-set threads. Spiral sculpture of three prominent rounded cords narrower than interspaces with a fourth partly covered by the anterior suture, cords intermittently weakly beaded where crossed by axial threads. Aperture subquadrate; outer lip simple; columella smooth. Anterior canal short, well developed. No siphonal fasciole.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 15.19, holotype	13.5	2.2	1.2	19
WAM 15.20, paratype	8.2	1.7		13+
WAM 15.21, paratype	10.3	2.2		14+
NMV P332349, paratype	11.6	2.0		14+

ETYMOLOGY

Latin adjective derived from Greek. Stenos narrow; pyrgiskos a little tower.

REMARKS

Seila species are spongophores, which probably accounts for the relative abundance of this species in the Walpole fauna. Despite this abundance no specimen is complete. This species has some resemblance to the southern Australian living species *Seila albosutura* (Tenison Woods, 1876), but is much narrower and more elongate. The narrow spire distinguishes the species from most Australian living species. In degree of narrowness, it resembles *Seila gagei* Maxwell from the middle Eocene of New Zealand, but the whorls are flatter and the spiral sculpture is not as coarse.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Genus *Cerithiopsis* Forbes & Hanley, 1850

Cerithiopsis pustuloclathrata sp. nov.

Figures 4.6–8

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MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 69.136.

Paratypes

WAM 72.291a from type locality. NMV P302244 from type locality.

Other material

From type locality: 27 specimens (WAM 67.119, 72.291, 15.22–3; NMV P302244, P327568–70). Lucky Bay via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, Merivale 264386. 2 specimens (WAM 04.182, 05.36). Total 31 specimens.

DIAGNOSIS

Shell with four thick lirae crossed by thick costae producing prominent nodules over whole whorl.

DESCRIPTION

Shell narrowly conical, very elongate, of small size for genus (5–13 mm), sutures slightly impressed, of about 6–9 very slightly convex whorls; last whorl contracting abruptly to anterior canal. Protoconch of 2½ whorls, first whorl slightly tilted, axially ribbed, second whorl with more prominent axial costae, abruptly merging with teleoconch. Spiral sculpture of four thick lirae. Axial sculpture of moderately thick costae, slightly narrower that interspaces with prominent nodules where crossed by spiral sculpture, about 28 costae on last and penultimate whorls. Last whorl with one thick, non-nodulose anterior lira corresponding to suture and completely covered by previous whorls. Last whorl smooth anterior to fifth lira. Aperture subrectangular, slight trace of posterior notch. Anterior canal short and slightly twisted. No siphonal fasciole.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 69.136, holotype	12.7	4.7	1.2	9+ slightly crushed
WAM 72.291a, paratype	9.1	2.7	1.1	
NMV P302244, paratype	10.6	3.5	1.7	9+

ETYMOLOGY

Latin adjective. Pustula a blister; clathrate latticed.

REMARKS

This species has some resemblance to *Cerithiopsis maresi* (Deshayes, 1864), Lutetian, Paris Basin, but has relatively flat-sided whorls when compared with that species.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Cerithiopsis? sp.

Figure 5.5

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: WAM 15.67–8; NMV P329296. Total specimens 4.

DESCRIPTION

Shell very narrow, elongate, whorls slightly convex with impressed sutures. Sculpture cancellate. Axial sculpture of 12–13 wide low costae, slightly narrower than interspaces. Spiral sculpture of four thin, erect lirae, much narrower than interspaces, developed into nodules at intersections with axial sculpture; anterior third lira slightly more prominent producing a very weak keel. Aperture subquadrate, produced anteriorly into short anterior canal.

DIMENSIONS

	Height	Width	No. of whorls
WAM 15.67	5.2	1.3	6+ specimen broken

REMARKS

The shell is extremely long and narrow and all specimens are broken. No protoconchs or complete apertures are preserved so generic placement is uncertain.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Cerithiopsid sp. 1

Figure 4.9

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: 1 specimen (WAM 15.268). Total specimens 1.

DIMENSIONS

	Height	Width	No. of whorls
WAM 15.268	5.5	1.9	9+ specimen broken.

REMARKS

This unique specimen is figured as there is nothing else quite like it in the fauna. Because the specimen lacks a protoconch and the aperture is broken it is not possible to assign it to a genus. It has some resemblance to species assigned to *Joculator* and *Horologia.*

OCCURRENCE

Eucla Basin: Pallinup Formation.

Cerithiopsid sp. 2

Figure 4.28

MATERIAL EXAMINED

Australia: Western Australia: Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: WAM 15.287. Total 1 specimen.

DIMENSIONS

	Height	Width	No. of whorls
WAM 15.287	4.9	1.4	6+ specimen broken

REMARKS

This unique specimen is figured as there is nothing else quite like it in the fauna. Because the specimen lacks a protoconch and the aperture is broken it is not possible to assign it to a genus.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Family Newtoniellidae Korobkov, 1955

Genus *Eocolina* Chavan, 1952

Eocolina sp.

Figure 4.33

MATERIAL EXAMINED

Australia: *Western Australia*: Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 69.138?, 82.1483, 04.146, 04.149?, 10.14, 15.264–5, NMV P317175, P329332–3. Total 23 specimens.

DESCRIPTION

Spire turreted of average size for genus (12–17 mm), of 9–10 rounded whorls. Protoconch of one axially plicate whorl merging imperceptibly into teleoconch whorls, coiled in axis of shell. First teleoconch whorl axially plicate. Plicae developing into broad costae by second teleoconch whorl; about 12–16 costae per whorl on mid spire. Spiral sculpture of about 6 to 8 lirae, wider than interspaces. Last whorl with low, broad varix situated just behind aperture. Spiral sculpture on anterior of last whorl very weak. Aperture ovate with slight posterior notch and short left directed anterior canal. Columella covered by a prominent plate.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 82.1483	14.7	5.1	2.9	9 + spire broken

REMARKS

This species has some resemblance to *Eocolina difficilis* (Deshayes, 1864) and *E. fayellensis* (Deshayes, 1864) both Eocene, France, but the sculpture is not cancellate as in those species. Most of the specimens are juveniles and some may not be conspecific with the others. No similar taxa are known from eastern Australia.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Genus *Ataxocerithium* Tate, 1894

Ataxocerithium concatenatum Tate, 1894

Figures 4.10, 4.29–30

Ataxocerithium concatenatum Tate, 1894: 179, plate 11, figure 6.

MATERIAL EXAMINED

Types

Australia: *South Australia*: SAM T241A–G from Adelaide and Aldinga. Tate's figured specimen (T241A) is chosen as lectotype to fix the status of the specimen as the sole name-bearing type of the species. The matrix suggests it came from the Adelaide (= Kent Town) Bore.

Paralectotypes

SAM T774B–G from Adelaide and Aldinga.

DIMENSIONS

	Height	Width	No. of whorls
SAM T241A, lectotype	10.4	4.6	7 spire broken
SAM T241E, lectoparatype	7.3	2.7	9
SAM T241F, lectoparatype	5.9	2.8	6 spire broken

REMARKS

Three of Tate's types are figured for comparison with the species from Thomson Rd, North Walpole. In his description of the species Tate did not mention that there are one or two plaits present on the columella and denticles within the outer lip on some specimens.

Ataxocerithium otopleuroides sp. nov.

Figures 4.12–13, 4.19–24

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MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 12.60.

Paratypes

WAM 05.52, 05.57a from Lucky Bay; 80.1335a from Cape Le Grand National Park. NMV P323139 from type locality.

Other material

From type locality. 161 specimens (WAM 67.97, 67.132, 69.192, 72.241, 72.287, 99.167, 04.150, 12.59, 12.61, NMV P323134–8). Lucky Bay via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, Merivale 264386. 8 specimens (WAM 04.183, 05.57b). Cape Le Grand National Park, old track surface, 3.7 km south-east of Frenchman Peak. 11 specimens (WAM 80.1335b, 80.1455, 85.641, 85.1459.). Total 182 specimens.

DIAGNOSIS

Shell tumid, somewhat convolute with numerous prominent axial costae crossed by weak close-set lirae.

DESCRIPTION

Shell of medium size for genus (13–17 mm), elongate, subconical with tumid last whorls and tapering spire. Protoconch damaged or missing on most specimens; seemingly of 2–3 smooth turbinid whorls, coiled in axis of shell. Spiral sculpture of 7–10 fine, weak, close-set lirae, as wide as interspaces. Axial sculpture of 35–50 costae, slightly wider than interspaces, weakly nodulate where crossed by spiral sculpture. Aperture subcircular; outer lip thickened with an internal rib; columella covered with thick callus forming a plate, two strong denticles present at base of anterior canal, which extend into aperture as plaits; one denticle bounding a slight posterior notch in aperture. Siphonal canal very short, twisted. No siphonal fasciole.

DIMENSIONS

	Height	Width	No. of whorls
WAM 12.60, holotype	10.3	5.7	5+
WAM 05.52, paratype	17.0		6+ specimen broken and crushed
WAM 05.57a, paratype	11.6	5.5	7+
WAM 80.1335a, paratype	11.5		5+ specimen broken and crushed
NMV P323139, paratype	12.6	6	8 specimen slightly crushed

ETYMOLOGY

In reference to its similarity in shape to species of the genus *Otopleura*.

REMARKS

Despite the apertural thickening, nearly every specimen has the outer lip peeled away, probably caused by crabs. This species has a close resemblance to *Ataxocerithium pellati* (Cossmann and Lambert, 1884) from the Oligocene of Pierrefitte, France, but doesn't have the cancellate appearance of that species as the axial costae are much stronger than the lirae. It also doesn't have the cancellate appearance of *A. concatenatum* Tate from the Blanche Point Formation.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Ataxocerithium venustulum sp. nov.

Figures 5.24–25, 5.36–37

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MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 12.65.

Paratypes

WAM 12.66 from type locality. NMV P319917 from type locality.

Other material

From type locality. 70 specimens (WAM 67.120, 99.166, 99.174, 04.147–8, 12.67, 12.68, 12.69, NMV P302237–9, P319916–7). Lucky Bay via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, Merivale 264386. 1 specimen (WAM 05.37). Cape Le Grand National Park, old track surface, 3.7 km south-east of Frenchman Peak. 3 specimens (WAM 80.1337, 85.1449, 85.1452.). Total 76 specimens.

DIAGNOSIS

Shell with five prominent spiral cords, cut into elongate beads by axial grooves.

DESCRIPTION

Shell of average size for genus (10–12 mm), turriculate of 8–9 somewhat flat whorls. Protoconch turbinate, of about 2½ finely ribbed whorls, coiled in axis of shell, ribs sharp, narrower than interspaces, merging imperceptibly with teleoconch. Spiral sculpture dominant of five prominent cords. Axial sculpture of 13–14 low, coarse costae, about as wide as interspaces, becoming weaker on last whorl, weakly tuberculate where crossed by spiral sculpture. Aperture subrectangular, with posterior denticle bounding posterior notch in aperture. Columella with prominent plate and two plaits at posterior canal. Siphonal canal short and twisted. Outer lip of aperture swollen forming a low varix. Weak siphonal fasciole.

DIMENSIONS

	Height	Width	No. of whorls
WAM 12.65, holotype	11.5	3.9	8
WAM 12.66, paratype	12.6	4.1	8
NMV P319917, paratype	10.3	3.8	8

ETYMOLOGY

Latin adjective. Diminutive of venustus beautiful.

REMARKS

This species is characterised by the dominant spiral sculpture, which separates it from the other similar sized cerithiopsids in the Walpole fauna. Nothing like this taxon is known from South Australia or Victoria. It bears some resemblance to the New Zealand late Eocene *Ataxocerithium scitulum* Maxwell, 1992, but the lirae are more prominent and the costae less prominent. The whorls are also flatter than the latter.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Ataxocerithium multicostulatum sp. nov.

Figures 5.26–27, 5.34–35

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MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 12.75.

Paratypes

WAM 12.76 from type locality. NMV P319918 from type locality.

Other material

From type locality: WAM 65.118a, 67.121, 69.137?, 9.139, 69.175b, 69.193, 72.284, 72.285, 72.293, 99.165, 04.169, 12.72, 12.73, 12.74, 12.76; NMV 302235, P302240, P302242–3, P319915, P319918. Total specimens 300.

DIAGNOSIS

Shell with somewhat convex whorls bearing broad axial ribs and fine lirae in rib interspaces.

DESCRIPTION

Shell subconical, turreted of medium size for genus (5–9 mm) of about 6 whorls, last whorl contracting abruptly to siphonal canal; sutures impressed. Protoconch of 2½ whorls bearing fine ribs narrower than interspaces and merging imperceptibly into teleoconch whorls. Axial sculpture of broad ribs, about 17–19 per whorl, wider than interspaces, extending from suture to suture on spire, absent on anterior half of last whorl, or becoming obsolete on some specimens. Spiral sculpture of eight fine lirae on spire whorls, 20+ on last whorl extending onto siphonal canal, slightly narrower than interspaces. Aperture with outer lip slightly reflexed dorsally and thickened on some specimens, lenticular, notched posteriorly, with prominent columella plate bearing two tubercles, absent on some specimens. Siphonal canal very short, reflexed dorsally.

DIMENSIONS

	Height	Width	No. of whorls
WAM 12.75, holotype	8.0	3.5	6
WAM 12.76, paratype	5.2	2.5	5+
NMV P319918, paratype	8.1	3.2	6

ETYMOLOGY

Latin adjective. Multus many; costulatum small ribbed.

REMARKS

The preservation of many of the above listed specimens is very poor, so that some of the specimens included in this taxon may not be correctly identified. It seems that well developed apertures with columella plate and tubercles are only present on mature specimens. Many small specimens in the samples lack these. This species has some resemblance to the Australian living species *Ataxocerithium serotinum* (A. Adams, 1855) but is not as narrow and elongate and the spiral sculpture is not so prominent.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Ataxocerithium biaulax sp. nov.

Figures 5.28–31

urn:lsid:zoobank.org:act:EA9FFD60-03C0-459A-9B76-AA936A6E2194

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 12.51.

Paratypes

WAM 12.52 from type locality. NMV P319913 from type locality.

Other material

From type locality: WAM 67.121 in part, 67.126, 99.206, 04.145b, 12.53, 12.62, 12.63, 12.64: NMV P302241, 319912–4. Total 47 specimens.

DIAGNOSIS

Shell cyrtoconoid with impressed sutures and convex whorls, smooth except for two prominent grooves adjacent to anterior and posterior sutures.

DESCRIPTION

Shell of small size (7–10 mm), cyrtoconoid, of about 7–8 whorls. Protoconch of 2½ finely costate whorls, costal interspaces wider than costae, merging abruptly into teleoconch whorls. Whorls slightly convex, sutures impressed. Spiral sculpture consisting of prominent groove immediately anterior to posterior suture and one slightly less prominent groove immediately posterior to anterior suture, otherwise smooth. Aperture subcircular with prominent smooth columella plate; prominent siphonal notch. Siphonal canal short, slightly twisted. Weak siphonal fasciole.

DIMENSIONS

	Height	Width	No. of whorls
WAM 12.51, holotype	9.0	3.9	8
WAM 12.52, paratype	7.5	3.1	6
NMV P319913, paratype	8.8	3.5	7

ETYMOLOGY

Latin noun in apposition. Biaulax two furrows.

REMARKS

This species is characterised by the relative smooth whorls, having merely two spiral grooves, which separates it from the other species of *Ataxocerithium* which have prominent axial costae and usually some lirae.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Genus *Eumetula* Thiele, 1912

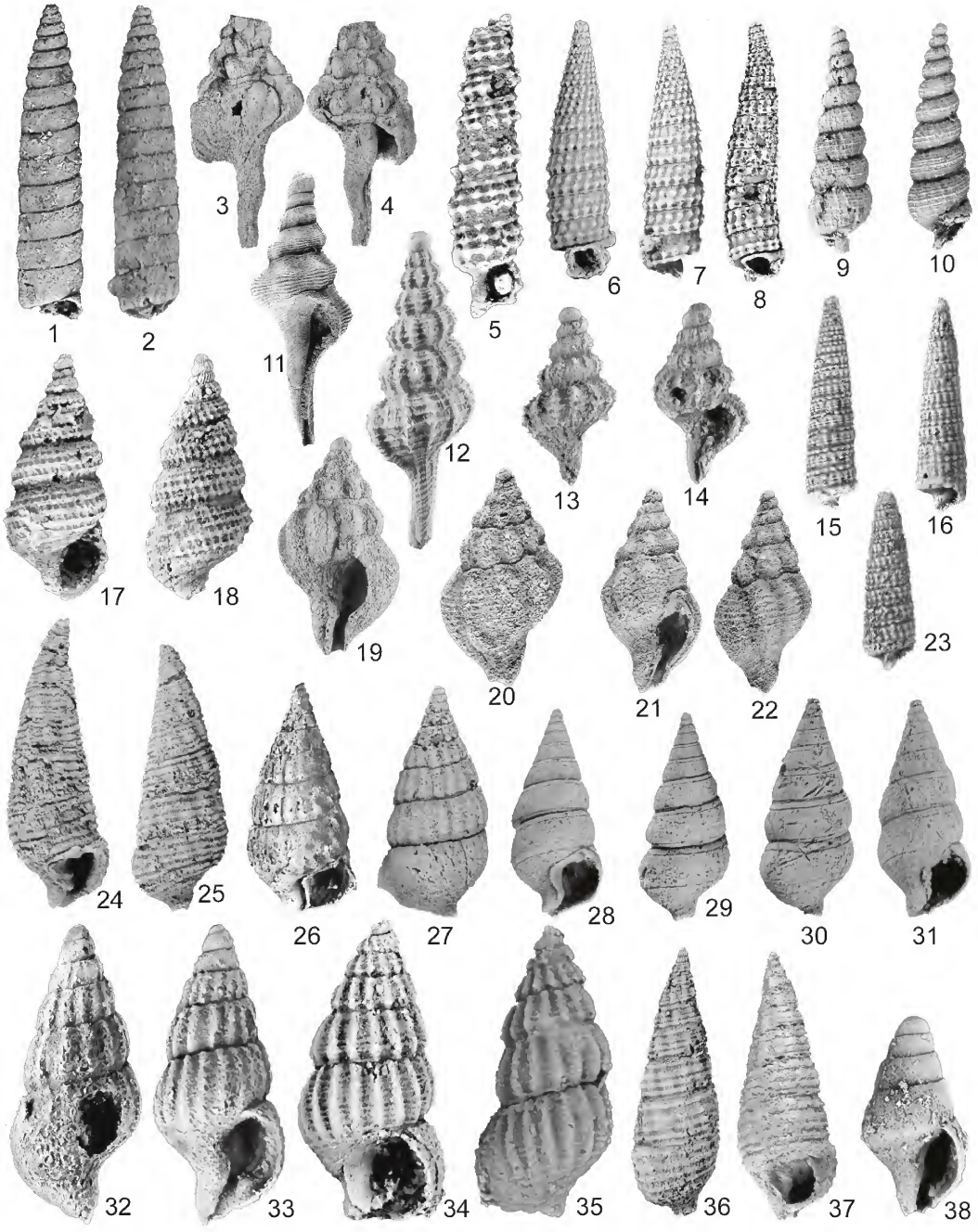
Eumetula sp.

Figures 5.17–18

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. 9 specimens (WAM 67.187, 15.81–2; NMV P329306–7). Total 9 specimens.

FIGURE 5 1, 2, *Trituba* sp.: 1, 2, WAM 15.293 (x 10);
3, 4, *Austrolithes* c.f. *A. incompositus* (Tate, 1888): 3, 4, WAM 12.32 (x 1);
5, *Cerithiopsis?* sp.: 5, WAM 15.293 (x 10);
6, 7, 8, *Trituba (Granulotriforis) umboseriata* sp. nov.: 6, 7, WAM 12.78 (x 5) holotype; 8, WAM 12.80 (x 5) paratype;
9, 10, *Cerithiella* sp.: 9, 10, WAM 15.78 (x 5);
11, *Austrolithes incompositus* (Tate, 1888): 11, SAM T492A (x 1.5) lectotype, Blanche Point;
12, 13, 14, *Fusinus sculptilis* (Tate, 1888): 12, SAM T478F (x3) syntype, Adelaide bore; 13, 14, WAM 12.07 (x 7);
15, 16, 23, *Cerithiella limula* sp. nov.; 15, 16, WAM 15.74 (x 5) holotype; 23, WAM 15.75 (x 5) paratype;
17, 18, *Eumetula* sp.: 17, 18, WAM 15.81 (x 10);
19, 20, 21, 22, *Tasmeuthria? arenicola* sp. nov.: 19, 20, WAM 12.20 (x 4) holotype; 21, 22, WAM 12.21 (x 4) paratype;
24, 25, 36, 37, *Ataxocerithium venustulum* sp. nov.: 24, 25, WAM 12.66 (x 4) paratype; 36, 37, WAM 12.65 (x 4) holotype;
26, 27, 34, 35, *Ataxocerithium multicostulatum* sp. nov.: 26, 27, WAM 12.75 (x 5) holotype; 34, 35, WAM 12.76 (x 10) paratype;
28, 29, 30, 31, *Ataxocerithium biaulax* sp. nov.: 28, 29, WAM 12.51 (x 4) holotype; 30, 31, WAM 12.52 (x 5) paratype;
32, 33, *Retizafra* sp.: 32, 33, WAM 15.90 (x 10);
38, *Mitrella* sp.: 38, WAM 67.149 (x 7).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DESCRIPTION

Shell elongate, turbiniform of about five cancellate whorls with impressed sutures. Protoconch of three whorls, first whorl slightly deviated from shell axis, all whorls sculptured with fine axial costulae, much narrower than interspaces, merging abruptly into teleoconch. Axial sculpture of low, thin costulae, much narrower than interspaces, about 34 on penultimate whorl and about 32 on last whorl. Spiral sculpture of prominent lirae, wider than the axial costulae, weakly beaded where crossed by axial sculpture, five lirae on penultimate whorl and eight lirae on last whorl. Aperture subcircular with short anterior canal.

DIMENSIONS

	Height	Width	No. of whorls
WAM 15.81	4.3	1.6	5

REMARKS

This species has some resemblance to the Antarctic living species *Eumetula strebeli* (Thiele, 1912), but has narrower and more numerous lirae.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Genus *Trituba* Jousseaume, 1884

Trituba sp.

Figures 5.1–2

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 15.293. NMV P332364. Total 2 specimens.

DESCRIPTION

Shell cyrtoconoid, whorls flat, sutures slightly grooved. Protoconch not preserved. No spiral or axial sculpture. Aperture tubular (broken). Posterior canal produced into tube on dorsal side of last whorl. Anterior canal broken. Base of shell concave.

DIMENSIONS

	Height	Width	No. of whorls
WAM 15.293	5.4	1.0	14+

REMARKS

The last whorl of this species is similar to species of *Trituba*, but the shell is quite smooth. Nothing in the Australian fossil or Recent fauna is similar to it.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Subgenus *Trituba (Granulotriforis)* Kosuge, 1967

Trituba (Granulotriforis) umboseriata sp. nov.

Figures 5.6–8

urn:lsid:zoobank.org:act:5B2BA421-D6AC-4F29-A9EB-836427619317

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 12.78.

Paratypes

WAM 12.80 from type locality. NMV P319922 from type locality.

Other material

From type locality: WAM 67.122, 67.124, 67.127, 69.142–3, 69.148–9, 69.151c, 72.292(part), 99.171, 04.153, 12.77, 12.79, 12.81; NMV P302236, P302245–6, P319919–21. Total 366 specimens.

DIAGNOSIS

Shell slender with impressed sutures and two rows of prominent tubercles aligned from whorl to whorl.

DESCRIPTION

Shell very slender, elongate-conical, only tapering slightly posteriorly, of about 13–15 flat whorls. Sutures impressed. Protoconch of about 2½ whorls, sculptured with fine axial ribs narrower than interspaces. Spiral sculpture of two rows of very prominent tubercles; tubercles aligned from whorl to whorl and about as wide as interspaces. About 16 pairs of tubercles per whorl. Penultimate whorl with a third anterior row of tubercles developing against anterior suture. Last whorl very abruptly contracted to form a smooth, very slightly concave base. Aperture rectangular, entire, produced slightly into a rectangular tube. Posterior canal enclosed produced into a short tube, projecting dorsally. Anterior canal enclosed, produced into a short tube.

DIMENSIONS

	Height	Width	No. of whorls
WAM 12.78, holotype	8.9	2.3	13
WAM 12.80, paratype	9.0	2.2	15
NMV P319922, paratype	7.6	2.1	13

ETYMOLOGY

Latin adjective. Umbo knob; seriata arranged in rows.

REMARKS

Species of this subgenus are known ranging in age from Miocene to Recent in Europe, Japan, Australia and New Zealand. *Trituba (Granulotriforis) umboseriata* is very similar to *T. (G.) dujardini* (Mayer, 1862) from the Miocene of France. The protoconch, though present on very few specimens and not well preserved, seems to match that of *T. (G.) blacki* Marshall, 1977, Recent, New Zealand. The axially aligned rows of tubercles distinguishes this species from its congeners.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Genus *Cerithiella* Verrill, 1882

Cerithiella limula sp. nov.

Figures 5.15–16, 5.23

urn:lsid:zoobank.org:act:34C8D0B0-1E61-4B73-BB36-98E977BF6369

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 15.74.

Paratypes

WAM 15.75 from type locality. NMV P329302 from type locality.

Other material

From type locality: 27 specimens (WAM 67.189?, 15.76–7; NMV P329301, P329303). Ocumup No. 1 deep well, 59.5 m., Eucla Bay district. 2 fragments (WAM 95.372). Total 32 specimens

DIAGNOSIS

Shell acicular with flat whorls sculpted by broad flat costae and one narrow prominent beaded lira against anterior suture and two broad posterior lirae.

DESCRIPTION

Shell acicular of 10–12 flat whorls, last whorl abruptly contracting to anterior canal. Protoconch of about two whorls, the first whorl smooth and slightly deviated from axis of shell, second whorl with numerous thin axial costae, much narrower than interspaces, merging imperceptibly into teleoconch. Axial sculpture of broad, rather flat costae wider than interspaces. Spiral sculpture of one narrow but prominent beaded lira against the anterior suture and posteriorly two broad lirae, on some specimens almost merging together to form a single band with a shallow groove in the middle, lirae beaded where crossed by axial costae. Last whorl with two thin lirae bounding base of whorl. Aperture subrectangular, produced into short twisted canal; columella with one thin plait close to canal.

DIMENSIONS

	Height	Width	No. of whorls
WAM 15.74, holotype	7.4	1.7	12
WAM 15.75, paratype	6.1	1.8	10+ specimen broken
NMV P329302, paratype	5.3	1.6	10

ETYMOLOGY

Latin noun in apposition. Limula a little file.

REMARKS

The aperture is broken on all specimens. This species has some resemblance to the living New Zealand species *Cerithiella stiria* (Webster, 1906), but has more prominent axial costae.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Cerithiella sp.

Figures 5.9–10

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. 14 specimens (WAM 69.146–7, 15.78–80; NMV P329304–5). Total 14 specimens.

DESCRIPTION

Shell elongate with 7–10 convex, cancellate whorls with impressed sutures. Axial sculpture of thin costulae, much narrower than interspaces, very weak or absent on some specimens. Spiral sculpture of thin, well defined lirae, about seven on penultimate whorl and 6–10 on last whorl, somewhat irregularly spaced and slightly beaded where crossed by axial sculpture. Aperture seemingly subcircular with short anterior canal, slightly reflexed dorsally.

DIMENSIONS

	Height	Width	No. of whorls
WAM 15.78	7.8	2.2	9+ specimen broken

REMARKS

The material available is not well preserved enough for formal description. The apertures are broken on all specimens and no protoconchs are preserved except possibly on one specimen, which shows part of two whorls sculptured with thin costae much narrower than the interspaces. On some specimens the sculpture is relatively strongly cancellate and on others the spiral sculpture is weak to absent so the sculpture is either weakly cancellate or not at all cancellate.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Neogastropoda

Family Buccinidae Rafinesque, 1815

Genus *Tasmeuthria* Iredale, 1925

Tasmeuthria? arenicola sp. nov.

Figures 5.19–22

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 12.20.

Paratypes

WAM 12.21 from type locality. NMV P327597 from type locality.

Other material

From type locality: Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: 133 specimens (WAM 67.139 part, 69.164, 72.303, 12.22–23, 15.38, 15.92–3, 15.38; NMV P317507, P327586–7, P329316–8). Lucky Bay via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, Merivale 264386. 1 specimen (WAM 05.47). Total 134 specimens.

DIAGNOSIS

Shell with weak shoulder and very thick costae extending from shoulder to anterior suture crossed by very weak irregular lirae.

DESCRIPTION

Shell fusiform, tumid, with weak shoulder, of small size for genus (8–10 mm). Protoconch prominent of 1½ smooth whorls, the first deviated from axis of shell, merging abruptly into teleoconch. Spiral sculpture of very weak, low, irregularly sized lirae about as wide as interspaces, about 9–10 on penultimate whorl, 15–20 on last whorl and extending onto anterior canal. Axial sculpture of very thick costae as wide as interspaces, 8–9 on penultimate and last whorls, extending from shoulder to anterior suture on spire whorls. Aperture lenticular, produced into a short, slightly twisted canal. Interior of outer lip lirate on some specimens; columella with 3–5 weak elongate nodules on some specimens. Siphonal fasciole very weak.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 12.20, holotype	9.3	5.0	2.1	4½
WAM 12.21, paratype	8.7	4.4	1.9	4½
NMV P327597, paratype	9.0	4.5	2.3	4½

ETYMOLOGY

Latin adjective. Arenicola sand dwelling.

REMARKS

Most specimens are slightly worn, so the lirae are scarcely visible. This species resembles *Tasmeuthria clarkei* (Tenison Woods, 1876), Recent, south-east Australia, but is significantly smaller and the shoulder is much weaker.

OCCURRENCE

Eucla Basin, Pallinup Formation.

Family Columbellidae Swainson, 1840

Genus *Retizafra* Hedley, 1913

Retizafra sp.

Figures 5.32–33

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: WAM 67.170, 69.174, 69.175a, 69.191, 15.90–1; 15.285. NMV P329314–5, P332354. Total 23 specimens.

DESCRIPTION

Shell fusiform, of small size for genus (5–6.6 mm) with 4–5 slightly convex whorls. Protoconch smooth, two whorls, first whorl slightly deviated, merging imperceptibly into teleoconch. Axial sculpture of broad costae, slightly narrower than interspaces, 10–12 on last whorl. No obvious spiral sculpture. Aperture oval, produced into short anterior canal; interior of outer lip with 9–10 fine lirae on some specimens.

DIMENSIONS

	Height	Width	No. of whorls
WAM 15.90	5.2	2.2	4

REMARKS

This species has some resemblance to *Retizafra multicostata* (May), Recent, New South Wales and Tasmania, but has a more ovate rather than elongate aperture.

OCCURRENCE

Eucla Basin, Pallinup Formation.

Genus *Mitrella* Risso, 1826

Mitrella sp.

Figure 5.38

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road,

Deep River 743 486: WAM 67.149, 72.322, 15.284; NMV P332356. Total 8 specimens.

DESCRIPTION

Shell fusiform, of small size for genus (5 mm), with about three flat whorls with impressed sutures abruptly contracting to canal. Smooth except for very weak, fine lirae on anterior of last whorl and extending onto canal. Aperture elliptical, extending anteriorly into short canal; inner lip with about eight elongate denticles; columella smooth.

DIMENSIONS

	Height	Width	No. of whorls
WAM 67.149	5.0	2.6	3

REMARKS

This species has some resemblance to *Mitrella leucostoma* (Gaskoin, 1852), Recent, southern Australia, but the spire is not as conical as in that species and the whorls are flatter.

OCCURRENCE

Eucla Basin, Pallinup Formation.

Family Fasciolariidae Gray, 1853

Genus *Fusinus* Rafinesque, 1815

Fusinus sculptilis (Tate, 1888)

Figures 5.12–14

Fusus sculptilis Tate, 1888: 137, plate 10, figure 13.

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: 1 specimen (WAM 12.07).

DESCRIPTION

Shell fusiform, elongate of three whorls, of small size for genus. Protoconch of 1½ smooth whorls merging abruptly with teleoconch whorls, first whorl deviated 45° to axis of shell. Spiral sculpture of about five fine lirae, much narrower than interspaces. Axial sculpture of fine costae forming sharp tubercles at intersection with spiral sculpture, 13 costae on last whorl. Aperture D-shaped, broken, produced anteriorly into a prominent canal.

DIMENSIONS

	Height	Width	No. of whorls
WAM 12.07	4.5	2.4	3 specimen broken

REMARKS

This specimen closely matches specimens from the Blanche Point Formation and Browns Creek Formation. This species belongs to a group of Eocene species of *Fusinus* characterised by the European *F. porrectus* (Solander in Brander, 1766). One of Tate's syntypes of this species is figured for comparison (Figure 5.12). A lectotype has not been chosen because further work needs to be done to ascertain which specimens were figured and measured by Tate.

OCCURRENCE

Eucla Basin, Pallinup Formation. **St Vincent Basin**: Blanche Point Formation (type). **Otway Basin**: Browns Creek Formation.

Genus *Austrolithes* Finlay, 1931

Austrolithes cf. *A. incompositus* (Tate, 1888)

Figures 5.3–4

cf. Fusus incompositus Tate, 1888: 137, plate 3, figure 9.

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: WAM 12.32. Total 1 specimen.

DIMENSIONS

	Height	Width
WAM 12.32	40.04	19.9 spire broken and crushed

REMARKS

This crushed specimen bears a close resemblance to specimens of *Austrolithes incompositus* from the Browns Creek Formation. Another specimen (WAM 12.31) from the Thomson Road locality consists of a broken anterior canal with part of the columella plate and without the rest of the teleoconch. It probably belongs to this species. Two small juvenile specimens from Cape Le Grand track (WAM 80.1347) with similar sculpture may belong to this species. There are two specimens of this species from the Blanche Point Formation in Tate's collection. Specimen number T492A from Blanche Point, Aldinga, is the figured specimen (Figure 5.11). The other smaller, incomplete specimen, T492B, comes from the Kent Town (Adelaide) Bore. Tate's figured specimen (T492A) is chosen as lectotype to fix the status of the specimen as the sole name-bearing type of the species.

OCCURRENCE

Eucla Basin, Pallinup Formation. **St Vincent Basin**: Blanche Point Formation (type). **Otway Basin**: Browns Creek Formation.

Genus *Dennantia* Tate, 1888

Fractolatirus Iredale, 1936, Recent, New South Wales, is probably a synonym of *Dennantia*. The following fossil species are included in the genus. *Peristernia aldingensis* Tate, 1888; *Latirus tatei* Harris, 1897; *Dennantia cingulata* Tate, 1888; *Trophon (Enatimene)*

crassiliratus Chapple, 1941(?); *Peristernia lintea* Tate, 1888; *Leucozonia staminea* Tate, 1888; *Fusus ino* Tenison Woods, 1879; *Leucozonia tumida* Tate, 1888; *Sipho crebrigranosa* Tate, 1888; *Peristernia subundulosa* Tate, 1888; *Peristernia interlineata* Tate, 1888; *Pisania rostrata* Tate, 1888; *Pisania semicostata* Tate, 1888; *Trophon succinctus* Tenison Woods, 1879.

Dennantia aldingensis (Tate, 1888)

Figures 6.21–22, 6.28–31

Peristernia aldingensis Tate, 1888: 156, plate 8, figure 8a–b.

Brocchitas aldingensis (Tate): Ludbrook, 1973: plate 25, figure 33.

MATERIAL EXAMINED

Types

Australia: ***South Australia***. Blanche Point, Aldinga Bay. SAM T570A–L. Tate's figured specimen T570B is chosen as lectotype to fix the status of the specimen as the sole name-bearing type of the species.

Other material

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 67.161, 72.307, 79.1024, 99.183, 99.187, 99.192, 99.203(?), 04.164 (part), 04.167, 15.01–3, 15.275; NMV P327561–5. Total 71 specimens.

DESCRIPTION

Shell fusiform, of average size for genus (18–24 mm), elongate of 5–6 convex whorls. Last whorl contracted abruptly to siphonal canal. Protoconch of about 1.5 smooth, somewhat tumid whorls, merging abruptly with teleoconch, coiled at a slight angle to spire axis. First teleoconch whorl sculptured with fine, widely spaced costae. Axial sculpture of broad costae, 5–9 on penultimate whorl, tending to weaken and disappear on last whorl. Spiral sculpture of fine lirae, much narrower than interspaces, 12–14 lirae on penultimate whorl. Aperture subcircular with small posterior notch; outer lip internally lirate. Columella with small denticle at beginning of anterior canal, four weak plaits extending into aperture, each beginning with a small denticle. Anterior canal long, slightly twisted, about ¼ length of shell.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
SAM T570B, lectotype	25.4	14.4		5
SAM T570H, lectoparatype	23.4	12.1		6
WAM 79.1024	21.6	8.8	6.0	6
WAM 99.187a	18.2	17	6.2	5

REMARKS

Large specimens from the Pallinup Formation are crushed, but the overall shell shape and sculpture match specimens of the species from the Blanche Point Formation. It is possible that some of the poorly preserved juvenile specimens do not belong to this species. Specimens from all formations of its range are exceedingly variable in morphology. None of the specimens mounted on Tate's tablet can be matched with the figures, though Tate has written 'figd' in red ink under specimens T570B from Blanche Point and T570H from Adelaide bore. Both these specimens are figured here (Figures 6.30 and 6.31 respectively).

OCCURRENCE

Eucla Basin, Pallinup Formation. **St Vincent Basin**: Blanche Point Formation (type). **Otway Basin**: Browns Creek Formation.

Genus *Tectifusus* Tate, 1893

Tectifusus aldingensis (Tate, 1888)

Figures 6.9–13

Fusus aldingensis Tate, 1888: 172, plate 3, figure 10.

Fusus tholoides Tate, 1888: 172, plate 3, figure 11; Cossmann, 1901: 13, Figure 4, plate 1, figure 11.

Tectifus tholoides (Tate): Ludbrook, 1973: plate 25, figure 54.

MATERIAL EXAMINED

Types

Australia: ***South Australia***. Blanche Point, Aldinga Bay. SAM T482A–D. Tate's figured specimen T482C (Figures 6.12–13) is chosen as lectotype of *Fusus aldingensis* to fix the status of the specimen as the sole name-bearing type of the species.

Fusus tholoides: Kent Town (Adelaide) Bore. SAM T493A–B. Tate's figured specimen T493A (Figure 6.11) is chosen as lectotype of *Fusus tholoides* to fix the status of the specimen as the sole name-bearing type of the species.

Other material

Australia: ***Western Australia*:** Lucky Bay via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, Merivale 264386. WAM 07.183. Total 1 specimen.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 07.183	15.9	11.4	8.4	2 spire broken

REMARKS

Tate described two species from material which in fact represents a somewhat variable single species. I select *Fusus aldingensis* to have priority over *Fusus tholoides*, because it has plate priority and specimens are readily collectable at Blanche Point. Though *F. tholoides* has page priority, the type locality is Adelaide (Kent Town) bore and specimens cannot be recollected. The species is common at Blanche Point and Browns Creek. The single specimen from Lucky Bay closely matches specimens from Blanche Point and Browns Creek.

OCCURRENCE

Eucla Basin, Pallinup Formation. **St Vincent Basin**: Blanche Point Formation (type). **Otway Basin**: Browns Creek Formation.

Family Melongenidae Gill, 1871

Genus *Pugilina* Schumacher, 1817

Pugilina? sp.

Figures 6.23–24

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: WAM 67.146, 12.24, 12.25, 12.26; NMV P317504–6. Total 11 specimens.

DESCRIPTION

Shell elongate, fusiform, of small size for genus, of about six teleoconch whorls, with gradate spire and prominent shoulder bounded by sharp keel. Protoconch of 1½ smooth whorls, the first whorl deviated at about 45° to axis of shell. Axial sculpture of prominent, rather broad, short costae extending anteriorly from keel, sharply produced on keel and at every 120° costae more prominent having a varix-like appearance; very weakly developed on posterior whorl slope. Spiral sculpture of prominent cords narrower than interspaces, three on anterior whorl slope and 10 lirae on last whorl and another 10 on canal. Aperture very long, narrow, extending into a long canal. Internal surface of outer lip smooth. Columella internally lirate, with lirae corresponding to lirae of previous whorl.

DIMENSIONS

	Height	Width	No. of whorls
WAM 12.25	20.9	10.4	6

REMARKS

The assignment of this species to *Pugilina* is tentative as most of the species included in that genus are much larger than this and have a tropical distribution. This species bears a superficial resemblance to the southern Australian Eocene species *Tectifusus aldingensis* (Tate), but the latter does not have varix-like costae at every third of a whorl, which give the shell a triangular appearance when viewed posteriorly and the protoconch is quite different. *T. aldingensis* does not have internal lirae on the columella. There is nothing like this species known from the Tertiary formations of eastern Australia.

OCCURRENCE

Eucla Basin, Pallinup Formation.

Family Muricidae Rafinesque, 1815

Genus *Timbellus* de Gregorio, 1885

Timbellus calvus (Tate, 1888)

Figures 6.14, 6.19–20

Murex calvus Tate, 1888: 96, plate 1, figure 11.

Pterynotus (*Pterynotus*) *calvus* (Tate). Ludbrook, 1973: plate 25, figure 50.

Timbellus calvus (Tate): Merle, Garrigues and Pointier, 2011: 434, plate 95, figures 1–3.

MATERIAL EXAMINED

Types

Australia: ***South Australia*:** Aldinga and Adelaide. SAM T427A–C. Tate's figured specimen (T427B, Blanche Point, Aldinga) is chosen as lectotype to fix the status of the specimen as the sole name-bearing type of the species (Figure 6.14).

Other material

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: 101 specimens (WAM 67.142, 72.301, 99.184, 04.162, 10.17–19; NMV P317181–5). Lucky Bay via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, Merivale 264386. 1 specimen (WAM 05.43). Total 102 specimens.

DESCRIPTION

Shell fusiform of average size for genus (15–20 mm), about five teleoconch whorls, with three prominent foliaceous varices, continuous from whorl to whorl, situated 120° from one another. Varices with incipient spine at shoulder. Protoconch of 1½ smooth whorls, the first deviated from axis of shell. Spiral sculpture of fine lirae, much narrower than interspaces and continuing onto varices; four to five on penultimate whorl, up to 16 on last whorl and extending onto canal. One prominent tubercle at midpoint between varices. Aperture large, ovate, produced anteriorly into short, open canal, notched posteriorly; inner lip smooth, outer lip with six to seven denticles.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 67.142a	15.1	6.4	5.3	5

REMARKS

The Western Australian specimens closely match those from Browns Creek. Walpole specimens have a slight suggestion of a posterior labral spine but this is not well developed and they also show signs of an incipient groove in the varix at the shoulder.

OCCURRENCE

Eucla Basin, Pallinup Formation. **St Vincent Basin**: Blanche Point Formation (type). **Otway Basin**: Browns Creek Formation; Glen Aire Clay.

Genus *Dermomurex* Monterosato, 1890

Dermomurex silicatus sp. nov.

Figures 6.25–27

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MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. 14 specimens. WAM 15.42.

Paratypes

From type locality WAM 15.46; NMV P327593.

Other material

From type locality: WAM 69.161, 72.300, 99.186, 15.41–46; NMV P327592–6. Total 53 specimens.

DIAGNOSIS

Shell with very narrow, widely spaced lirae and five prominent foliaceous aligned varices.

DESCRIPTION

Shell narrowly fusiform, of average size for genus (15–29 mm), about five teleoconch whorls. Protoconch of 1½ smooth whorls, abruptly (?poorly preserved) merging with teleoconch. Spiral sculpture of thin lirae, much narrower than interspaces, 13–15 on last whorl and 4–5 on penultimate whorl (posterior lira very faint). Axial sculpture of five prominent, foliaceous varices aligned from whorl to whorl. Aperture elongate oval, produced into short canal; columella with denticle on some specimens but smooth in others, inner side of outer lip with three or more denticles on some specimens. Siphonal fasciole present on some specimens.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 15.42, holotype	24.0	9.9	7.9	5
WAM 15.46, paratype	29.0	14.6	8.0	5
NMV P327593, paratype	25.3	11.2	7.2	5

ETYMOLOGY

Latin adjective. Silicatus silicified.

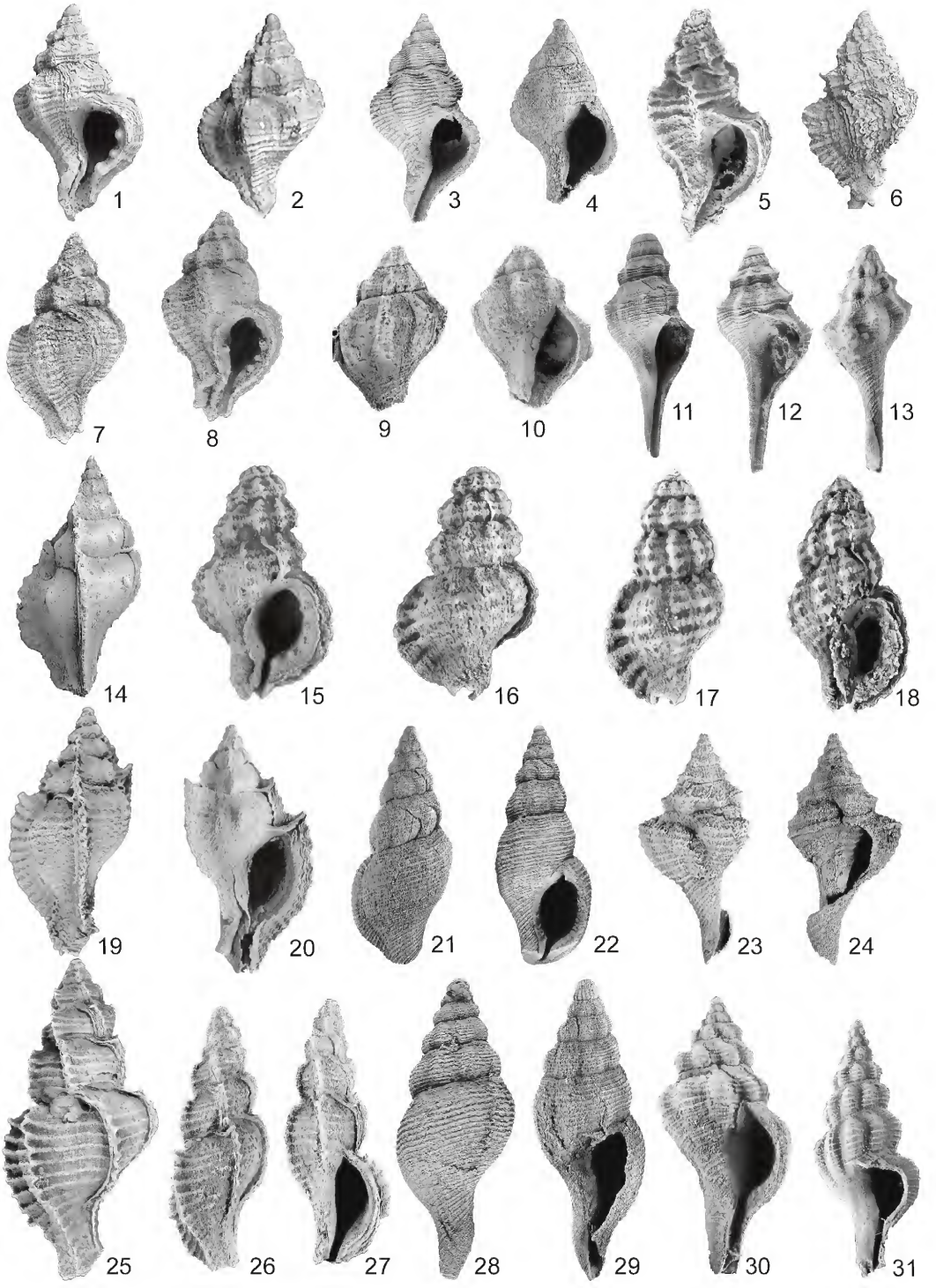
REMARKS

All specimens are somewhat worn and some of the worn juvenile specimens may not be this species. This species bears a close resemblance to *Dermomurex garrardi* Vokes, 1985, Miocene, Victoria, but differs in having very prominent thin lirae. Of other described species of the genus, this taxon has some resemblance to *Dermomurex bathyrhaphe* Lozouet, 1999 from the late Oligocene of France, but differs in having well developed thin lirae rather than broad low lirae.

OCCURRENCE

Eucla Basin, Pallinup Formation.

FIGURE 6 1, 2, 7, 8, *Hexaplex? tridentatus* (Tate, 1888): 1, 2, SAM T433 (x 4) holotype, Aldinga Bay; 7, 8, WAM 15.31 (x 3);
3, 4, *Attiliosa arenaria* sp. nov.: 3, WAM 12.10 (x 3) holotype; 4, WAM 12.11 (x 3) paratype;
5, 6, *Ocenebra prionotus* (Tate, 1888): 5, WAM 15.89 (x 5); 6, SAM T411C (x 2) lectotype, Adelaide bore;
9, 10, 11, 12, 13, *Tectifusus aldingensis* (Tate, 1888): 9, 10, WAM 07.183 (x 2); 11, SAM T493A (x 1.5), syntype of *Fusus tholoides* Tate, 1888, Adelaide bore; 12, 13, SAM T482C (x 1.5) lectotype, Aldinga;
14, 19, 20, *Timbellus calvus* (Tate, 1888): 14, SAM T427B (x 2) lectotype, Blanche Point; 19, 20, WAM 67.142a (x 3);
15, 16, 17, 18, *Dermomurex* sp.: 15, 16, WAM 67.141 (x 7); 17, 18, WAM 15.100 (x 7);
21, 22, 28, 29, 30, 31, *Dennantia aldingensis* (Tate, 1888): 21, 22, WAM 79.1024 (x 2); 28, 29, WAM 99.187a (x 3); 30, SAM T570B (x 2) lectotype, Blanche Point; 31, SAM T570H (x 2) paralectotype, Adelaide bore;
23, 24, *Pugilina?* sp.: 23, 24, WAM 12.25 (x 2);
25, 26, 27, *Dermomurex silicatus* sp. nov.: 25, WAM 15.46 (x 2) paratype; 26, 27, WAM 15.42 (x 2) holotype.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Dermomurex sp.

Figures 6.15–18

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: WAM 67.138, 69.141, 15.100, 15. 261-2; NMV P329324-5, P332359. Total 12 specimens.

DESCRIPTION

Shell somewhat tumid, fusiform, of small size for genus (6–7.5 mm), of about four convex whorls with impressed sutures. Protoconch of 1½ smooth whorls, first whorl deviated at about 45° from axis of shell, merging abruptly with teleoconch. Axial sculpture of broad, somewhat scabrose costae slightly narrower than interspaces, nodulose where crossed by spiral sculpture, five on penultimate whorl and 10 on last whorl and diminishing in strength adapically. Spiral sculpture of thick cords slightly narrower than interspaces, five on penultimate whorl and 6–8 on last whorl extending onto canal. Traces of apertural varices present on spire whorls. Aperture ovate, thickened externally into a frilled varix, internal lip with 4–5 denticles, columella covered with thin plate. Siphonal canal short narrow, twisted dorsally. Siphonal fasciole prominent.

MEASUREMENTS

	Height	Width	No. of whorls
WAM 15.100	7.2	3.5	4
WAM 67.141	6.1	4.6	4

REMARKS

The specimens are probably all juveniles and poorly preserved, so the generic assignment is tentative. Nothing similar is known from eastern Australia. This species has some resemblance to the Eastern Pacific species *Dermomurex obeliscus* (A. Adams, 1853) and *D. alabastrum* (A. Adams, 1864).

OCCURRENCE

Eucla Basin, Pallinup Formation.

Genus *Hexaplex* Perry, 1810

Hexaplex? tridentatus (Tate, 1888)

Figures 6.1–2, 6.7–8

Murex tridentatus Tate, 1888: 108, plate 2, figure 2.

MATERIAL EXAMINED

Holotype

Australia: South Australia: Aldinga Bay: SAM T433.

Other material

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: 191 specimens (WAM 67.137a, 67.141, 67.144a, 69.145; 69.159?, 69.162, 69.168, 72.304–5, 69.172?, 72.305, 79.1022, 04.161, 04.163, 15.31–6; NMV P317508–9, P327579–81, P329326). Lucky Bay via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, Merivale 264386. 2 specimens (WAM 04.190, 05.42). Cape le Grand National Park, 0.8 km NE of turnoff to Lucky Bay, west side of road, Merivale 428219: 1 specimen (WAM 07.195?) Total 194 specimens.

DESCRIPTION

Shell fusiform of average size for genus (7–14 mm), with about five to six somewhat tumid whorls. Protoconch of 1½ smooth whorls, the first slightly deviated from axis of shell. Spiral sculpture of thin lirae slightly narrower than interspaces, five to six on penultimate whorl, about 20 on last whorl extending onto canal. Axial sculpture of prominent, thick, foliaceous varices, somewhat irregularly spaced, five to six on last whorl. Aperture ovate, inner lip with three and rarely up to five prominent denticles. Columella with one and rarely another prominent denticle near canal. Canal short and slightly twisted. Siphonal fasciole prominent.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 15.31	12.8	7.1	4.1	5

REMARKS

Many specimens from Walpole are not very well preserved but sufficient numbers are present to show that they resemble the holotype (Figures 6.1–2) and also specimens from Browns Creek Formation. Only the holotype is known from the Blanche Point Formation. It has three denticles on the inner lip of the aperture and does not have a denticle on the columella. However, specimens from Walpole and Browns Creek show that these features vary in number. This species bears some resemblance to *Pterynotus (Pterymarchia) denudatus* (Deshayes, 1835), Middle–Late Eocene, Europe.

OCCURRENCE

Eucla Basin, Pallinup Formation. **St Vincent Basin**: Blanche Point Formation (type). **Otway Basin**: Browns Creek Formation.

Genus *Attiliosa* Emerson, 1958

Attiliosa arenaria sp. nov.

Figures 6.3–4

urn:lsid:zoobank.org:act:078DC9E9-5518-4177-BADD-288E10C3A2BF

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 12.10.

Paratypes

WAM 12.11, from type locality. NMV P327584 from type locality.

Other material

From type locality: 56 specimens (WAM 67.162, 69.167, 72.254, 72.302?, 99. 188, 12.12, 15.37; NMV P327582–3, P327585, P327588, P329327, P332353, P332355). Lucky Bay via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, Merivale 264386. 1 specimen (WAM 04.188). Total 57 specimens.

DIAGNOSIS

Shell with impressed sutures and thin, raised, widely spaced lirae and six prominent swollen costae per whorl.

DESCRIPTION

Shell tumid, fusiform of 4–6 whorls with impressed sutures. Spire subconical. Protoconch of 1¼ smooth whorls, first whorl slightly deviated from axis of shell, merging abruptly into teleoconch. Spiral sculpture of thin, raised lirae, very much narrower than interspaces, 11 on penultimate whorl and 28 on last whorl extending over whole whorl and down anterior canal, on some specimens lirae somewhat scabrous. Axial sculpture of prominent, swollen costae, six per whorl. Aperture lenticular produced anteriorly into a long, slightly twisted canal; outer lip internally lirate on some specimens. Siphonal fasciole prominent.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 12.10, holotype	25.3	13.5	7.2	6
WAM 12.11, paratype	11.2	7.0	3.7	4
NMV P327584, paratype	20.0	10.2	8.0	4+

ETYMOLOGY

Latin adjective. Arenaria pertaining to sand.

REMARKS

This species has some resemblance to *Ocenebra asperula* (Tate, 1888), Miocene, Otway and Port Phillip Basins. It differs by having a more conical spire, less scabrose lirae and having six rather than 8–9 costae per whorl.

OCCURRENCE

Eucla Basin, Pallinup Formation.

Genus *Ocenebra* Gray, 1847

Ocenebra prionotus (Tate, 1888)

Figures 6.5–6

Murex prionotus Tate, 1888: 107, plate 1, figure 5.

Murexsul prionotus (Tate): Ludbrook, 1973: plate 25, figure 45.

MATERIAL EXAMINED

Types

Australia: ***South Australia*:** Kent Town Bore, Adelaide, South Australia, T411A–G. Tate's figured specimen T411C is chosen as lectotype to fix the status of the specimen as the sole name-bearing type of the species (Figure 6.6).

Other material

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: WAM 15.83-4, 15.89; NMV P329308–9. Total 361 specimens.

DIMENSIONS

	Height	Width	No. of whorls
WAM 15.89	8.5	4.7	4

REMARKS

Specimens from Thomson Road are all juveniles and relatively smaller in size than specimens from South Australia and Victoria, but otherwise seem to match specimens from Blanche Point and Browns Creek Formations as well as small specimens on Tate's tablet of syntypes from the Kent Town Bore.

OCCURRENCE

Eucla Basin, Pallinup Formation. **St Vincent Basin**: Blanche Point Formation (type). **Otway Basin**: Browns Creek Formation.

Genus *Coralliophila* H. & A. Adams, 1853

Coralliophila (s.l.) sp.

Figures 7.20–22, 7.26–27

MATERIAL EXAMINED

Australia: ***Western Australia*****:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: WAM 67.148, 69.163, 72.246, 72.308a, 99.185, 15.39–40, 15.276; NMV P327589–91. Total 30 specimens.

DESCRIPTION

Shell of average size for genus (16–32 mm), fusiform, whorls somewhat tumid with impressed sutures. Protoconch of two smooth whorls merging imperceptibly into teleoconch, first whorl deviated from shell axis. Spiral sculpture of thin, erect lirae, narrower than interspaces, scabrose where crossed by axial sculpture, 13 on penultimate whorl, about 28 lirae on last whorl. Axial sculpture of very broad costae, 7–9 on posterior whorls decreasing in size and fading on last whorl, plus numerous thin, raised lamellae forming delicate scales on crossing lirae. Prominent raised cord on last whorl emerging from posterior suture and continuing to outer lip where it forms a small labral tooth. Growth lines form a v shape over cord. Aperture ovate, produced into short straight canal. Columella and inside surface of outer lip smooth. No siphonal fasciole. Prominent umbilicus present.

DIMENSIONS

	Height	Width	No. of whorls
WAM 67.148	32	21	5 shell distorted and canal broken
WAM 99.185a	22.8		5 shell distorted and canal broken
WAM 72.308a	13.0	8.8	4
WAM 72.246	15.9	7.4	4

REMARKS

This species is somewhat similar to *Attiliosa arenaria* sp. nov. but is distinguished by the presence of an umbilicus and the scabrose sculpture. It resembles somewhat the Indo-Pacific *Coralliophila abnormis* (Smith, 1878), but the protoconch of the Walpole species doesn't seem to be pustulate as in that species, however, the Walpole specimens are worn and broken and such delicate sculpture may have been abraded off. It also has some resemblance to *C. mira* (Cotton and Godfrey, 1932) from southern Australia, but has much more inflated whorls.

OCCURRENCE

Eucla Basin, Pallinup Formation.

Genus Laevityphis Cossmann, 1903

Laevityphis ludbrookae Keen & Campbell, 1964

Figures 7.17–19

Typhis tripterus Tate, 1888: 93, plate 3, figure 14 (non Grateloup, 1833).

Laevityphis (Laevityphis) ludbrookae Keen and Campbell, 1964: 52, plate 10, figures 33, 34, 36 (nom. nov. for *Typhis tripterus* Tate, 1888 non Grateloup, 1833).

Laevityphis (Laevityphis) ludbrookae Keen & Campbell: Ludbrook, 1973: plate 25, figure 46.

MATERIAL EXAMINED

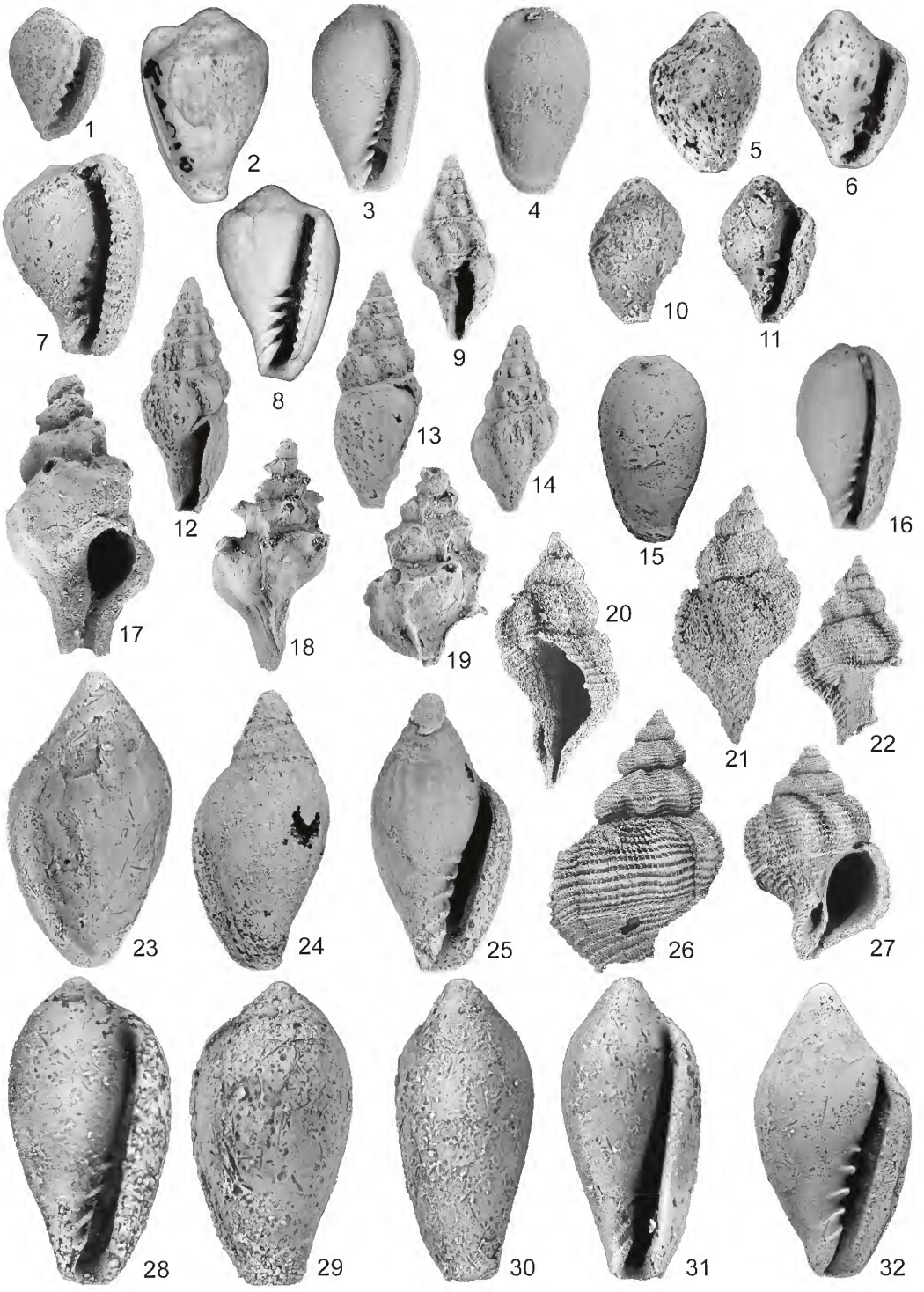
Syntypes

Australia: South Australia: Adelaide (Kent Town) Bore: SAM T453A–B.

Other material

Australia: ***Western Australia*****:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: 1 specimen (WAM 12.06).

FIGURE 7 1, 5, 6, 10, 11, *Ovaginella arenula* sp. nov.: 1, WAM 15.281 (x 10) paratype; 5, 6, WAM 15.12 (x 10), paratype; 10, 11, WAM 15.11 (x 10) holotype;
2, 8, *Serrata mala* (Cotton, 1949): 2, 8, SAM P4016 (x 4) holotype, Aldinga (Photo: Alexis Tindall, South Australian Museum).
3, 4, 15, 16, *Cryptospira hordeastra* sp. nov.: 3, 4, WAM 12.87 (x 5) holotype; 15, 16, WAM 15.88 (x 5) paratype;
7, *Serrata* cf *S. mala* (Cotton, 1949): 7, WAM 82.1488 (x 5);
9, 12, 13, 14, *Cordieria torquata* sp. nov.: 9, 14, WAM 12.58 (x 5) paratype; 13, 14, WAM 12.57 (x 5) holotype;
17, 18, 19, *Laevityphus ludbrookae* Keen & Campbell, 1964: 17, SAM T453A (x 3) paralectotype, Adelaide bore; 18, SAM T453B (x 4) lectotype, Adelaide bore; 19, WAM 12.06 (x 3);
20, 21, 22, 26, 27, *Coralliophila* sp.: 20, 21, WAM 72.246 (x 3); 22, WAM 99. 185 (x 1.5); 26, WAM 67.148 (x 1.5); 27, WAM 72.308a (x 3);
23, 24, 25, 32, *Eratoidea fusoides* sp. nov.: 23, 32, WAM 12.84 (x 5) holotype; 24, 25, WAM 12.85 (x 5) paratype;
28, 29, 30, 31, *Ovaginella mumiformis* sp. nov.: 28, 29, WAM 15.10 (x 10) paratype; 30, 31, WAM 15.09 (x 10) holotype.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DESCRIPTION

Protoconch missing, four teleoconch whorls remaining. Shell elongate of average size for genus. Spire gradate with impressed sutures and prominent shoulder bearing short tubes, broken in this specimen. Last whorl abruptly contracted to anterior canal (broken). Sculpture of thin varices extending from shoulder anteriorly, about four varices per whorl, not present on posterior whorl slope of shoulder.

DIMENSIONS

	Height	Width	No. of whorls
WAM 12.06	6.5	4.0	4 specimen broken

REMARKS

The unique Walpole specimen, though broken, is sufficiently well preserved to enable it to be identified. Keen and Campbell (1964) stated that the holotype of the species was T453B, but Tate, who mentioned he had two specimens, did not chose a holotype. In terms of Article 73.1 of the International Code of Zoological Nomenclature this specimen is not the holotype and Tate's specimens are syntypes. It is not clear which of the two specimens mentioned by Tate was figured, however, specimen T453B is the better preserved of the two and most likely the figured specimen. This specimen T453B is chosen as the lectotype to fix the specimen as the sole name-bearing type of the species. Both of Tate's specimens are figured here (Figures 7.17 paralectotype, 7.18 lectotype).

OCCURRENCE

Eucla Basin, Pallinup Formation. **St Vincent Basin**: Blanche Point Formation (type). **Otway Basin**: Browns Creek Formation; Glen Aire Clay.

Family Marginellidae Fleming, 1828

Genus *Eratoidea* Weinkauff, 1879

Eratoidea fusoides sp. nov.

Figures 7.23–25, 7.32

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MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 12.84.

Paratypes

WAM 12.85 from type locality. NMV P323143 from type locality.

Other material

From type locality: 22 specimens (WAM 72.313, 72.317, 99.195, 99.197, 04.171a, 12.82–3, 12.86 NMV P323142, P323144–6). Lucky Bay via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, Merivale 264386. 1 specimen (WAM 05.51). Cape Le Grand National Park, old track surface, 3.7 km south-east of Frenchman Peak 2 specimens (WAM 80.1326, 80.1352). Total 28 specimens.

DIAGNOSIS

Shell almost biconical, spire conical. Outer lip of aperture finely denticulate. Columella with five equal plaits.

DESCRIPTION

Shell smooth, broadly fusiform, almost biconic, of large size for the genus (9–11 mm), with conical spire about one third height of shell. Protoconch dome-shaped, smooth. Aperture moderately wide; columella with five equal plaits; outer lip with very weak denticulations along entire length of inner surface, thickened into prominent varix on some specimens. Siphonal notch barely visible.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 12.84, holotype	10.7	5.5	6.7	4
WAM 12.85, paratype	10.2	5.1	6.6	4
NMV P323143, paratype	9.1	5.4	6.5	4

ETYMOLOGY

Latin adjective. Fusoides resembling a spindle.

REMARKS

This species is unlike any other Australian taxon. It is distinguished by the conical spire, denticulate outer lip and the presence of five equal plaits on the columella. Specimens of a marginellid from the Late Eocene near Kalbarri, Western Australia (Darragh and Kendrick, 2008) are somewhat similar in size and general shape, though somewhat more elongated, but are too poorly preserved for precise comparison.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Genus *Cryptospira* Hinds, 1844

Cryptospira hordeastra sp. nov.

Figures 7.3–4, 7.15–16

urn:lsid:zoobank.org:act:978F7FB3-98E1-4A2B-AF67-A84D47F197CC

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 12.87.

Paratypes

WAM 12.88 from type locality. NMV P323148 from type locality.

Other material

From type locality: WAM 67.169, 69.185a, 72.314, 82.1489, 99.194, 04.170, 12.89–90, 15.04–5; NMV P323147, P323149, P327189–91. Total 116 specimens.

DIAGNOSIS

Shell pyriform, last whorl almost enveloping earlier whorls. Outer lip of aperture smooth internally and with prominent varix.

DESCRIPTION

Shell of average size for genus (6.5–8.3 mm), elongate, pyriform, spire very low, last whorl almost enveloping earlier whorls. Protoconch smooth, of about one whorl coiled in axis of teleoconch, merging imperceptibly with teleoconch whorls. Aperture narrow, elongate, posteriorly extended and overlapping onto spire whorls; outer lip smooth internally, thickened externally into prominent varix. Columella with four equal plaits and one or two weak plications posteriorly that do not extend into the aperture. No siphonal notch.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 12.87, holotype	6.9	3.9	6.4	3
WAM 12.88, paratype	6.8	4.0	6.2	3
NMV P323148, paratype	7.0	4.0	6.5	3

ETYMOLOGY

Latin adjective. Hordeastra like a barley seed.

REMARKS

This species has some resemblance to *Marginella doma* Cotton, 1949 from the Dry Creek Sands, South Australia, but differs in not having a denticulated outer apertural lip. There is nothing like it in the Eocene formations of the St Vincents and Otway Basins.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Genus *Ovaginella* Laseron, 1957

Ovaginella mumiformis sp. nov.

Figures 7.28–31

urn:lsid:zoobank.org:act:5E3D965D-BFAB-4F04-8AFB-39ABC1054F19

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 15.09.

Paratypes

WAM 15.10 from type locality. NMV P327195 from type locality.

Other material

From type locality: 135 specimens (WAM 67.163, 67.165, 69.182, 69.185b, 72.315, 99.193, 99.196, 04.171b, 04.172, 15.06-8; NMV P327192–4, P327571). Lucky Bay via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, Merivale 264386. 1 specimen (WAM 05.50). Cape Le Grand National Park, old track surface, 3.7 km south-east of Frenchman Peak 1 specimen (WAM 85.640). Total 140 specimens.

DIAGNOSIS

Shell elongate with conical spire and outer lip smooth internally. Columella with four strong plaits.

DESCRIPTION

Shell of average size for genus (5–6 mm), smooth, elongate pyriform; spire low, conical, barely projecting. Protoconch of one smooth whorl, coiled in axis of shell, merging imperceptibly with teleoconch whorls. Aperture narrow, elongate; outer lip internally smooth, externally thickened into prominent varix. Columella with four strong, equal-sized plaits. No siphonal notch.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 15.09, holotype	5.5	2.5	4.0	3
WAM 15.10, paratype	5.6	3.0	4.4	3
NMV P327195, paratype	6.5	3.1	4.8	3

ETYMOLOGY

Latin adjective. Mumiformis having the shape of a mummy.

REMARKS

This species is similar in shape to the Victorian Miocene species *Marginella propinqua* Tate, 1878 and *M. woodsi* Tate, 1878, but lacks the denticles present on the inside of the outer lip of those species.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Ovaginella arenula sp. nov.

Figures 7.1, 7.5–6, 7.10–11

urn:lsid:zoobank.org:act:7D85829D-9E11-4559-997C-B6D90A91188C

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 15.11.

Paratypes

WAM 15.12, 15.281 from type locality. NMV P327196 from type locality.

Other material

From type locality: WAM 69.184, 15.11-13; NMV P327197–8. Total 41 specimens.

DIAGNOSIS

Shell small, biconical with outer lip smooth internally. Columella with fourt plaits.

DESCRIPTION

Shell of small size for genus (2.5–3.5 mm), smooth, tumid, biconical. Protoconch of one smooth whorl, coiled in axis of shell, merging imperceptibly with teleoconch whorls. Aperture relatively wide, elongate; with prominent posterior notch; outer lip internally smooth, externally thickened into prominent varix. Columella with four strong, equal-sized plaits. No siphonal notch.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 15.11, holotype	2.7	1.8	2.0	3
WAM 15.12, paratype	2.9	2.0	2.3	3
WAM 15.281, paratype	2.5	1.8		3
NMV P327196, paratype	3.3	2.1	2.6	3

ETYMOLOGY

Latin noun in apposition. Arenula a grain of sand.

REMARKS

This species is very small like *Marginella aldingae* Tate, 1878, but the spire is much more conical and there are no costae on the whorls as in the latter.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Genus *Serrata* Jousseaume, 1875

Serrata cf. *S. mala* (Cotton, 1949)

Figure 7.7

Marginella mala Cotton, 1949: 215, plate 18.

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: WAM 82.1488. NMV P329279. Total 2 specimens.

DIMENSIONS

	Height	Width	Aperture height
WAM 82.1488	7.5	5.4	6.0

REMARKS

The better preserved specimen has a more rounded last whorl rather than having the very slight shoulder present on specimens of *Serrata mala* (Cotton) from South Australia, but otherwise closely resembles it. This is the only marginellid in the fauna that seems to be identical to a species from the Eocene of South Australia and Victoria. The holotype of *Marginella malla* Cotton, SAM P4016 from Blanche Point Formation, Aldinga, is figured for comparison (Figures 7.2, 7.8).

OCCURRENCE

Eucla Basin: Pallinup Formation. **St Vincent Basin**: Blanche Point Marl (type). **Otway Basin**: Browns Creek Formation.

Family Volutidae Rafinesque, 1815

Genus *Lyria* Gray, 1847

Lyria craticulata sp. nov.

Figures 8.35–39

rn:lsid:zoobank.org:act:15F82D58-44A9-4F9A-9232-B74C5081027D

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 09.03a.

Paratypes

WAM 09.03b, 12.37 from type locality. NMV P332352 from type locality.

Other material

From type locality: 213 specimens (WAM 67.153–5, 67.157, 67.159, 67.176, 69.179, 69.180, 69.186, 72.247, 72.257, 72.310, 72.311, 72.312?, 99.198, 04.174, 12.33, 12.34, 12.36. NMV P317770–73). Lucky Bay via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, Merivale 264386. 7 specimens (04.189, 04.193, 05.53, 05.54, 05.55b). Cape Le Grand National Park, old track surface, 3.7 km south-east of Frenchman Peak 15 specimens (WAM 80.1348–51, 85.638, 85.1456). Cape le Grand National Park, 0.8 km NE of turnoff to Lucky Bay, west side of road, Merivale 428219: 3 specimens (WAM 07.194). Little Wharton Bay, near Mt Belcher, Duke of Orleans Bay: 1 specimen (WAM 05.176a). Total 231 specimens.

DIAGNOSIS

Shell, fusiform with weak shoulder. Sculpture cancellate of fine lirae crossed by coarse or fine costae.

DESCRIPTION

Shell elongate, fusiform of small size for genus (20–43 mm) with subturbinate spire, weak shoulder and impressed sutures. Whorls five to six with subsutural groove and row of nodules corresponding to axial sculpture between it and suture. Protoconch of 1½ smooth whorls, first whorl slightly deviated from axis of shell. Spiral sculpture of lirae about as wide as interspaces, seven to 10 lirae on spire whorls, tuberculate where crossed by axial sculpture, 16 lirae on last whorl and extending onto canal. Axial sculpture highly variable, on some specimens consisting of stout costae about 10 on last whorl and 16 on spire whorls becoming coarser and indistinct towards aperture; on other specimens consisting of up to 45 very narrow costae producing a cancellate appearance where crossed by spiral sculpture. Aperture, where preserved, lenticular, outer lip with prominent interior tubercle situated about ¾ the distance along lip posteriorly. Columella with four prominent plaits, becoming stronger posteriorly and with one or two narrow spiral ridges posterior to plaits. Canal short with weak siphonal notch and weak siphonal fasciole.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 09.03a, holotype	25.7	12.6	11.1	5+
WAM 09.03b, paratype	28.2	12.9		6
WAM 12.37, paratype	33.7	14	17	6
NMV P332352, paratype	30.6	13.5	15.6	5

ETYMOLOGY

Latin adjective. Craticulata latticed.

REMARKS

This is one of the most common species in the Pallinup Formation at Thomson Road. All specimens are distorted to some extent and most seem to have suffered attacks by crabs. Only one specimen has the aperture preserved. This species shows a high degree of morphological variability. It does not resemble any species previously recorded from Australia. This is the second species of *Lyria* recorded from the Eocene of Western Australia. *Lyria lamellatoplicata* Darragh and Kendrick, 2008 from Kalbarri has a prominent shoulder and no subsutural groove.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Genus *Mitreola* Swainson, 1833

Mitreola salaputium Darragh, 1989

Figures 8.1–2

Mitreola salaputium Darragh, 1989: 215, plate 1, figures 10, 11, 15, 16.

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: 20 specimens (WAM 79.386 holotype, 89.976,. 99.199a, 12.34, 12.36; NMV P50005–6, P50007 paratype, P317774–6, P329328). Cape Le Grand National Park, old track surface, 3.7 km south-east of Frenchman Peak: 2 specimens (WAM 80.1346, 85.1454). Total 22 specimens.

DESCRIPTION

Shell of small size for genus (9.5–12.9 mm), ovately fusiform. Protoconch of 1½ smooth whorls, first of which slightly deviated from axis of shell. Axial sculpture of thick, low costae as wide as interspaces present on spire whorls, but absent from last whorl. No spiral sculpture. Aperture narrowly lenticular; outer lip thickened with small internal denticle; inner lip covered with thick callus; columella with four prominent plaits and posterior denticle. Siphonal notch and siphonal fasciole weakly developed.

DIMENSIONS

	Height	Width	Aperture height
WAM 12.34	9.5	4.3	4.3

REMARKS

As Darragh (1989) noted this is the only record of the genus known from Australia. The range of the species has been extended from the occurrence on Thomson Road to Cape Le Grand National Park.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Genus *Notopeplum* Finlay, 1927

Notopeplum cf. *N. protorhysum* (Tate, 1889)

Figures 8.29–30

Voluta protorhysa Tate, 1889:126, plate 2, figures 6a–b.

Notopeplum protorhysum (Tate). Darragh 1989: 256, 257, plate 25, figures 7, 10, 11, figure 31 (with synonymy). Darragh and Kendrick, 2008: 239, Figures 3.16–17.

MATERIAL EXAMINED

Australia: *Western Australia*: Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: 50 specimens (WAM 67.160, 69.181, 72.248, 12.38, 12.39, 12.40, 12.41, 12.42. NMV P317777–80). Cape le Grand National Park, 0.8 km NE of turnoff to Lucky Bay, west side of road, Merivale 428219: 2 specimens (WAM 06.161, 07.197?). Cape Le Grand National Park, old track surface, 3.7 km south-east of Frenchman Peak, 2 specimens (WAM 85.1456). Lucky Bay via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, Merivale 264386: 1 specimen (WAM 05.55a). Total 55 specimens.

DESCRIPTION

Shell elongate fusiform, of average size for genus (30–48 mm). Protoconch of 1½ whorls, first somewhat irregular, smooth, next whorl plicate, plicae enlarging to form costae on teleoconch whorls. Teleoconch sculpture of stout costae, narrower than interspaces present on first two or three teleoconch whorls then becoming weaker and fading adaperturally. Aperture elongate, lenticular with slightly thickened out lip Columella with four strong and one to three weaker posterior plaits. Siphonal notch and fasciole weak.

DIMENSIONS

	Height	Width	Aperture height	No. of whorl
WAM 12.38	37.8	14.5	17.4	5

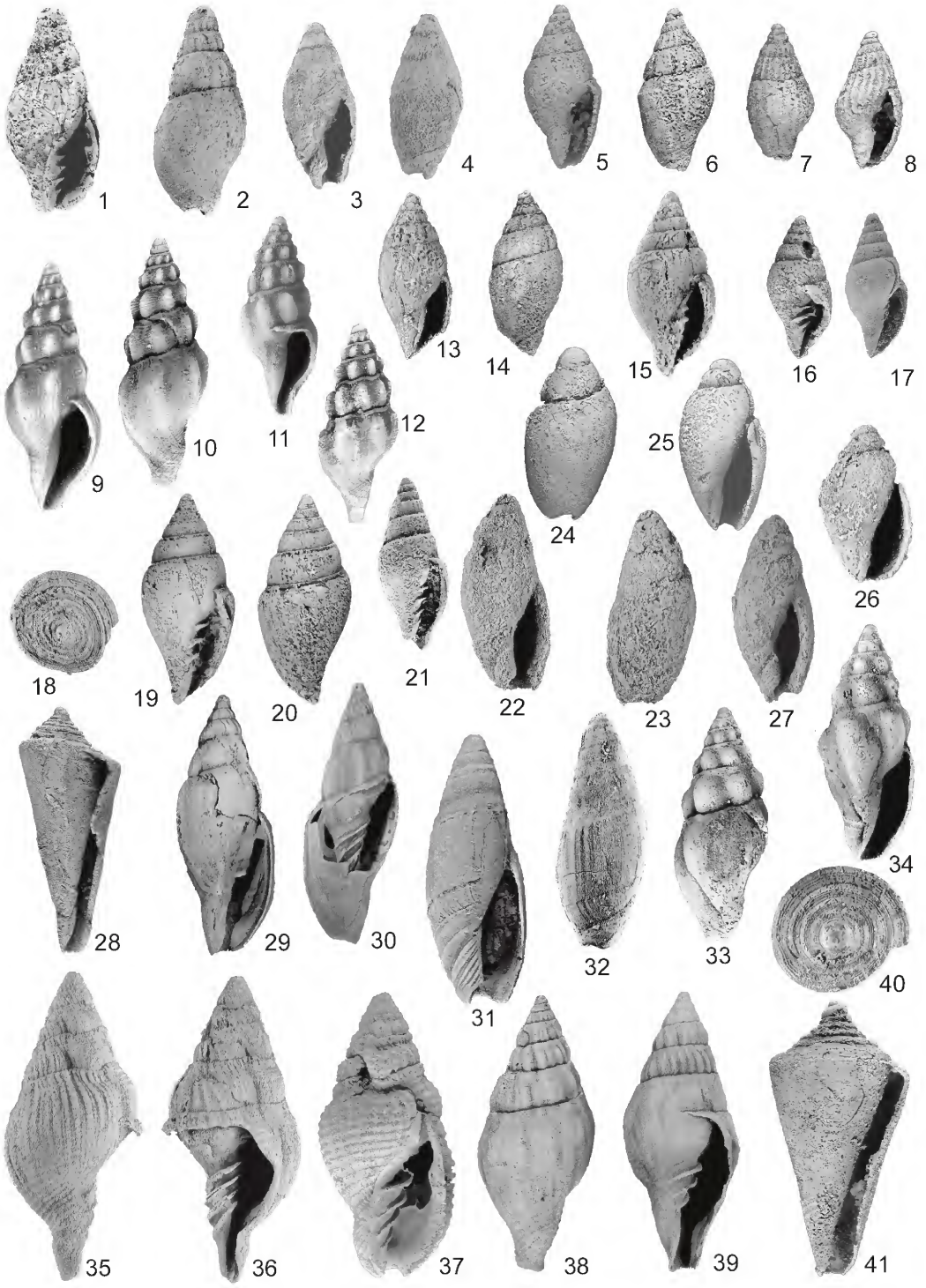
DISCUSSION

The overall shape of the specimens, particularly those from Lucky Bay and Cape Le Grande, is very similar to Tate's figured specimen from the Kent Town Bore, Adelaide, though Walpole specimens tend to be not so prominently shouldered. This may be due to variation typical of many volute taxa, or less likely an artefact of preservation.

OCCURRENCE

Southern Carnarvon Basin: unnamed sandstone. Middle–Late Eocene. **Eucla Basin**: Pallinup Formation. **St Vincent Basin**: Blanche Point Formation (type). **Otway Basin**: Browns Creek Formation.

FIGURE 8 1, 2, *Mitreola salaputium* Darragh, 1989: 1, 2, WAM 12.34 (x 4);
3, 4, 22, 23, 27, 31, 32, *Amalda (Gracilispira) ligata* (Tate, 1889): 3, 4, WAM 12.28 (x 5); 22, 23, WAM 12.30 (x 5); 27, WAM 12.27 (x 5); 31, SAM T700C (x 2) lectotype, Adelaide bore; 32, SAM 700H (x 2) paralectotype, Adelaide bore?;
5, 6, 7, 8, 13, 14, *Conomitra strombodiformis* sp. nov.: 5, 6, WAM 12.13 (x 6) holotype; 7, 8, WAM 12.15 (x 7) paratype; 13, 14, WAM 12.14 (x 6) paratype;
9, 10, 11, 12, 33, 34, *Cordieria fuscoamnica* sp. nov.: 9, 10, NMV P33348 (x 5) holotype, Browns Creek; 11, 12 NMV P329287 (x 5) paratype; 33, 34, WAM 99.202 (x 2) paratype;
15, 16, *Microvoluta* cf. *M. complanata* (Tate, 1889): 15, WAM 99.191b (x 5); 16, WAM 12.09 (x 4);
17, *Microvoluta complanata* (Tate, 1889): 17, SAM T643 (x 2) holotype, Adelaide bore;
18, 28, 40, 41, Conus sp.: 18, 28, WAM 10.06 (x 2); 40, 41, WAM 10.07 (x 4);
19, 20, *Microvoluta* cf. *M. subcrenularis* (Tate, 1889): 19, 20, WAM 99.191a (x 3);
21, *Microvoluta subcrenularis* (Tate, 1889): 21, SAM T647B (x 2) syntype, Adelaide bore;
24, 25, 26, *Belloliva canaliculata* sp. nov.: 24, 25, WAM 12.18 (x 8) holotype; 26, WAM 12.19 (x 7) paratype;
29, 30, *Notopeplum* cf. *N. protorhysum* (Tate, 1889): 29, 30, WAM 12.38 (x 1.25);
35, 36, 37, 38, 39, *Lyria craticulata* sp. nov.: 35, 36, WAM 09.03b (x 2) paratype; 37, WAM 09.03a (x 2) holotype; 38, 39, 12.37 (x 1.5) paratype.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Family Volutomitridae Gray, 1854

Genus *Conomitra* Conrad, 1865

Conomitra strombodiformis sp. nov.

Figures 8.5–8, 8.13–14

urn:lsid:zoobank.org:act:F01E527E-46B9-4044-BEA1-177D71F0C4B7

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** WAM 12.13 from Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486.

Paratypes

WAM 12.14–5, NMV P317786 from type locality.

Other material

From type locality: WAM 67.158, 69.178, 12.16, 12.50, 15.279; NMV P317785, P317787, P332351. Total 50 specimens.

DIAGNOSIS

Shell tumid, fusiform with coarse costae on some or all whorls and fine lirae on anterior whorl slope of last whorl.

DESCRIPTION

Shell small for genus (4–5 mm), tumid, fusiform of about four to five whorls, with subconical spire. Protoconch of about 1½ smooth whorls; first whorl slightly tilted. Four to five teleoconch whorls. Axial sculpture of 20–26 coarse costae about as wide as interspaces, usually present on some or all whorls, rarely absent. Spiral sculpture of about 10 lirae on anterior whorl slope of last whorl. Aperture elliptical, produced into short canal; columella with two plaits, interior of outer lip with three to seven irregular plicae.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 12.13, holotype	4.9	2.4	2.4	4
WAM 12.14, paratype	5.0	2.2	2.2	4
WAM 12.15, paratype	3.6	1.7	2.1	4
NVP P317786, paratype	5.0	2.0	2.0	4

ETYMOLOGY

Latin adjective from Greek. Strombodiformis in the shape of a top.

REMARKS

This species bears a close resemblance to *Conomitra fusoides* (Lea, 1833), Eocene, USA, type species of the genus, but is not as tumid. It is not very similar to other Australian species of the genus.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Genus *Microvoluta* Angas, 1877

Microvoluta cf. *M. subcrenularis* (Tate, 1889)

Figures 8.19–20

Mitra subcrenularis Tate, 1889: 142, pl. 5, figure 6.

Waimatea subcrenularis (Tate). Ludbrook, 1973: plate 25, figure 25.

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: 10 specimens (WAM 99.191a, 99.201(?), 15.94, 15.288?; NMV P319910, P329319, P332358?). Lucky Bay via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, Merivale 264386: 2 specimens (WAM 05.45). Total 12 specimens.

DESCRIPTION

Shell fusiform, somewhat tumid, of average size for genus (12 mm), with imbricated sutures. Protoconch of two smooth whorls. Teleoconch of six whorls. Spiral sculpture of a single groove just anterior to posterior suture and a few obscure grooves on anterior whorl slope of last whorl. Axial sculpture of low, close-set costae, about 40 on penultimate whorl, cut by spiral groove and produced into row of small tubercles against posterior suture. Aperture narrow, slightly elliptical, produced anteriorly into short anterior canal. Columella with four plaits, three posterior the strongest.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 99.191a	12.7	5.6	6.7	6

REMARKS

The specimens are more tumid than specimens of *Microvoluta subcrenularis* from the Blanche Point Formation and the axial sculpture is much finer than on the latter. Some specimens are much worn and

assignment to the species is somewhat uncertain. A syntype of *M. subcrenularis*, SAM T647B, Adelaide bore, possibly Tate's figured specimen is figured for comparison (Figure 8.21).

OCCURRENCE

Eucla Basin: Pallinup Formation.

Microvoluta cf. *M. complanata* (Tate, 1889)

Figures 8.15–16

Mitra complanata Tate, 1889: 138, pl. 5, figure 12.

Waimatea complanata (Tate). Ludbrook, 1973: plate 25, figure 24

MATERIAL

Australia: *Western Australia*: Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: 9 specimens (WAM 99.191b, 12.09, 15.99; NMV P319911). Lucky Bay via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, Merivale 264386: 2 specimens (WAM 05.46, 05.68). Total 11 specimens.

DESCRIPTION

Shell fusiform, smooth, tumid, of average size for genus (12 mm), with imbricated sutures and somewhat turreted spire. Protoconch poorly preserved of about two smooth whorls. Teleoconch of five whorls. No visible sculpture. Aperture narrow, slightly elliptical, produced anteriorly into short anterior canal. Columella with three to four plaits, three posterior the strongest

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 12.09	6.5	3.0	3.5	5
WAM 99.191b	6.8	3.4	3.3	4+ specimen broken

REMARKS

The specimens are too poorly preserved for precise determination, but bear a very close resemblance in overall morphology to specimens of *Microvoluta complanata* from the Browns Creek Formation and the holotype from the Kent Town Bore (Figure 8.17), though the Walpole specimens are much smaller than those from Browns Creek.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Family Olividae Latreille, 1789

Genus *Amalda* H. & A. Adams, 1853

Subgenus *Gracilispira* Olson, 1956

Amalda (Gracilispira) ligata (Tate, 1889)

Figures 8.3–4, 8.22–23, 8.27, 8.31–32

Ancillaria ligata Tate, 1889: 147, plate 7, figure 6.

Baryspira (*Gracilispira*) *ligata* (Tate): Ludbrook: 1973, plate 25, figures 55–56.

MATERIAL EXAMINED

Types

Australia: *South Australia*: Blanche Point, Aldinga; Adelaide (Kent Town) Bore, Adelaide, (SAM T700A–R). Tate's figured specimen (T700C, Adelaide (Kent Town) bore) is chosen as lectotype to fix the status of the specimen as the sole name-bearing type of the species (Figure 8.31, paralectoype Figure 8.32).

Paralectotypes

SAM T700A-B, D-R.

Other material

Australia: *Western Australia*: Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: (WAM 72.309, 12.27–30; NMV P317500-1, P317788). Total 15 specimens.

DESCRIPTION

Shell narrowly fusiform, with tall, narrow spire, small for the species. Protoconch smooth, of about 1½ whorls. Spire callus scarcely visible. Columella with three plaits.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 12.27	6.4	2.8	3.1	3
WAM 12.28	10.1	4.5	5.2	3
WAM 12.30	7.1	3.1	3.0	3

REMARKS

All Walpole specimens are small and not very well preserved, but seem identical to small and middle sized specimens of this species from the Blanche Point Formation and the Browns Creek Formation, in both of which small specimens are common. The specimen recorded by Darragh and Kendrick (2008) as *Gracilispira* sp. cf. *G. ligata* (Tate) from the unnamed Eocene Sandstone near Kalbarri, WA, looks somewhat more tumid than specimens from Walpole, but this could be an artefact of preservation as many specimens from Walpole are slightly distorted.

OCCURRENCE

Eucla Basin, Pallinup Formation. **St Vincent Basin**: Blanche Point Formation (type). **Otway Basin**: Browns Creek Formation.

Family Olivellidae Troschel, 1869

Genus *Belloliva* Peile, 1922

Belloliva canaliculata sp. nov.

Figures 8.24–26

urn:lsid:zoobank.org:act:C8CC1A52-4FC7-4EB4-9D00-3BB6DD479BAC

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** WAM 12.18 from Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486.

Paratypes

WAM 12.19, NMV P317503 from type locality.

Other material

From type locality: WAM 67.151, 69.177, 12.17; NMV P317502. Total 33 specimens.

DIAGNOSIS

Shell small, smooth, fusiform with channelled suture. No plaits on columella.

DESCRIPTION

Shell smooth, glossy, ovately fusiform, with channelled sutures. Small for genus (3–4.5mm). Protoconch of about 1½ smooth whorls merging imperceptibly with teleoconch. Whorls two to three. Aperture lenticular, moderately wide, with prominent siphonal notch. Columella with no visible plaits.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 12.18, holotype	3.9	2.0	1.9	2
WAM 12.19, paratype	4.1	2.1	2.2	2
NMV P317503, paratype	4.0	2.2	2.1	2½

ETYMOLOGY

Latin adjective. Canaliculata channelled.

REMARKS

This species is somewhat similar in morphology to *Belloliva adelaidae* (Tate, 1889), Blanche Point Formation, South Australia. It has the same canaliculated suture, but is much smaller, lacks prominent plaits, is not as elongate, and the protoconch is much smaller. Similar differences separate it from the species recorded by Darragh and Kendrick (2008) as *Gemmoliva* sp. cf. *G. adelaidae* from the unnamed Eocene Sandstone near Kalbarri, WA.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Family Conidae Fleming, 1822

Genus *Conus* Linnaeus, 1758

Conus sp.

Figures 8.18, 8.28, 8.40–41

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: 28 specimens (WAM 67.179, 69.187, 99.204, 04.175, 10.06–7, 15.282–3; NMV P316331–3). Cape Le Grand National Park, old track surface, 3.7 km south-east of Frenchman Peak: 1 specimen (WAM 80.1354). Total 29 specimens.

DESCRIPTION

Shell of medium size for genus, up to 27 mm high. Protoconch of 2½ smooth, turbiniform whorls, coiled in axis of shell and protruding above teleoconch whorls. Teleoconch of five to six whorls, biconic with very low spire. Sculpture present on whorl shoulder of about five thin, equally spaced spiral threads, much narrower than interspaces. Last whorl anterior to shoulder smooth, except for 5–10 weak lirae at the anterior of the whorl.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 10.06	22.3	10.0 (max)	17.2	9 slightly squashed laterally
WAM 10.07	12.5	6.3	10.1	4

REMARKS

An internal mould of a possible species of *Conus* was recorded by Darragh and Kendrick (2008) from the late Eocene sandstone at Kalbarri, Western Australia No species of *Conus* are known from the Eocene formations of the St Vincent or Otway basins. The earliest occurrence of the genus in eastern Australia is in the Late Oligocene Jan Juc Formation. The preservation of the specimens varies somewhat and the better preserved material is slightly distorted. Most of the specimens are fragments. This species bears some resemblance to the

Victorian Miocene species *Conus pullulescens* Tenison Woods, 1879 in respect to the protoconch, but lacks the spiral sculpture covering the last whorl in that species. It has a general resemblance to the low-spired forms of *C. sauridens* Conrad, 1833, Eocene, United States of America. A laterally compressed internal mould (WAM 84.1027) from the Pallinup Formation at Mt Barker, Plantaganet loc 6129, west side Barrow Rd, may possibly be this species. It has four lirae on the shoulder. Indeterminate internal moulds of *Conus* have been found in the Nannarup Limestone quarry (WAM 69.250) and at Bremer Bay (G6053) (but possibly actually from Balladonia). Both the latter specimens do not bear any resemblance to the Walpole material.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Family Borsoniidae Bellardi, 1875

Genus *Cordieria* Rouault, 1848

Cordieria fuscoamnica sp. nov.

Figures 8.9–12, 8.33–34

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?*Cordieria* sp. a. Long, 1981: 33, plate 5, figure 11.

MATERIAL EXAMINED

Holotype

Australia: ***Victoria*:** NMV P33348, from locality PL3011, Browns Creek Formation, dark gritty clay, below greensand, washout nearest Brown Creek, Johanna, Victoria, Glenaire 079 058.

Paratypes

P329287 from type locality. WAM 99.202 from **Australia:** ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486.

Other material

From type locality 9 specimens (NMV P33373, P42908, P329286, 329288–9). From Walpole

25 specimens (WAM 72.318, 15.54–6; NMV P329283–5). Total 37 specimens.

DIAGNOSIS

Shell narrowly fusiform with prominent coarse costae and fine lirae. Columella with two weak plaits on most specimens.

DESCRIPTION

Shell of average size for genus (7–10 mm), narrowly fusiform, of about five whorls with narrow concave shoulder. Protoconch of 1½ smooth whorls, the first whorl slightly deviated from axis of shell, abruptly merging into teleoconch. Axial sculpture of prominent coarse costae extending from shoulder to anterior suture, narrower than interspaces, becoming weaker on last quarter of last whorl, seven costae on penultimate whorl. Spiral sculpture of fine lirae about as wide as interspaces, about 11 on penultimate whorl and about 37 on last whorl extending onto anterior canal. Aperture narrowly elliptical with very short anterior canal and shallow anal sinus. Siphonal fasciole weakly developed. Columella with two weak plaits present on some specimens.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
NMV P33348, holotype	9.0	3.3	3.2	5
NMV P329287, paratype	7.3	2.8	2.0	5
WAM 99.202, paratype	8.8	3.4	3.7	5

ETYMOLOGY

Latin adjective. Fuscus brown; amnica pertaining to a stream.

REMARKS

Specimens from Walpole are slightly wider than those from Browns Creek. The plaits are very weak and not present on all specimens which caused Long (1981) to record this taxon as doubtfully *Cordieria*. However, the shape, sculpture and presence of two plaits on some specimens indicate that it does belong in the genus. As Long pointed out the species has a close resemblance to *C. rudis* (Hutton, 1885) from the Eocene of New Zealand. The Australian species is more slender, with much finer and more numerous lirae and more prominent costae.

OCCURRENCE

Eucla Basin: Pallinup Formation. **Otway Basin**: Browns Creek Formation (type).

Cordieria torquata sp. nov.

Figures 7.9, 7.12–14

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MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 12.57.

Paratypes

WAM 12.58 from type locality. NMV P323133 from type locality.

Other material

From type locality: 1218 specimens (WAM 67.143, 69.169, 69.188, 72.245, 72. 306, 82.1487, 99.189, 99.190, 04.165, 04.166, 12.54, 12.55, 12.56, 12.57. NMV P317789, P323130–3). Lucky Bay via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, Merivale 264386: 3 specimens (04.191, 05.49). Cape Le Grand National Park, old track surface, 3.7 km south-east of Frenchman Peak: 6 specimens (WAM 80.1344). Little Wharton Bay, near Mt Belcher, Duke of Orleans Bay: 1 specimen (WAM 05.175). Total 1225 specimens.

DIAGNOSIS

Shell narrow with prominent subsutural cord and broad close-set costae. Columella with two prominent plaits.

DESCRIPTION

Shell narrow, fusiform of average size for genus (6–14 mm). Teleoconch of 4–4½ whorls. Protoconch of 1½ smooth whorls coiled in axis of shell, merging abruptly into teleoconch whorls. Spiral sculpture consisting of a thin subsutural cord. Axial sculpture of prominent thick, rounded costae, slightly wider than interspaces, extending on spire whorls from subsutural cord to anterior suture, six costae on last whorl. Last whorl contracting abruptly to short anterior canal. Siphonal fasciole scarcely visible. Aperture elongate, D shaped; outer lip prosocyrt with a very shallow posterior sinus against suture; inner lip with two plaits, the posterior the strongest.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 12.57, holotype	8.6	3.0	3.6	5
WAM 12.58, paratype	6.8	3.2	3.2	4½
NMV P323133, paratype	8.4	3.2	4.0	4½

ETYMOLOGY

Latin adjective. Torquata collared.

REMARKS

This is the second most common gastropod at Walpole. This species is very similar to *Cordieria fuscoamnica* sp. nov. but is distinguished by the presence of the subsutural cord and the plaits are quite prominent just within the aperature whereas in the former they are hiden. It has a close resemblance to *C. brevicula* (Deshayes, 1834) Eocene, France, but has a subsutural cord lacking in that species and is more elongate.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Family Cochlespiridae Powell, 1942

Genus *Apiotoma* Cossmann, 1889

Apiotoma sp.

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: WAM 67.175. 1 specimen.

REMARKS

The single specimen is a fragment consisting of the protoconch and five teleoconch whorls. It seems to be the same species as that figured by Long (1981, plate 4, figure 14) from the Browns Creek Formation.

OCCURRENCE

Eucla Basin: Pallinup Formation. **Otway Basin**: Browns Creek Formation.

Family Conorbidae de Gregorio, 1880

Genus *Conorbis* Swainson, 1840

Conorbis notialis sp. nov.

Figures 9.26–29

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MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** WAM 67.167 from Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486.

Paratypes

WAM 12.43, NMV P317782 from type locality.

Other material

From type locality: 16 specimens (WAM 72.319, 99.200; 12.44–5; NMV P316338–40, P317783). Lucky Bay via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, Merivale 264386. 1 specimen (WAM 04.192).

Cape Le Grand National Park, old track surface, 3.7 km south-east of Frenchman Peak, 1 specimen (WAM 85.1453). Cape Le Grand National Park, 0.8 km NE of turnoff to Lucky Bay, Merivale 428219. 3 specimens (WAM 07.193). Total 24 specimens.

DIAGNOSIS

Shell biconic, tumid, with fine lirae on anterior half of last whorl and thin groove adjacent to posterior suture of whorls.

DESCRIPTION

Shell of small size for genus, up to 11.8 mm high, fusiform, somewhat tumid, biconic, spire slightly gradate, about ⅓ height of shell. Protoconch of 1½ smooth, dome-shaped whorls, axis slightly deviated from axis of shell. Four to five slightly convex teleoconch whorls. Sculpture of about 10–13 faint lirae on anterior half of last whorl, extending onto siphonal canal. Thin groove present immediately anterior to posterior suture. Last whorl convex posteriorly, anteriorly attenuating to a short canal. Aperture narrow, elongate, outer lip sinuous with wide, shallow posterior sinus. Siphonal canal short.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 67.167, holotype	9.2	3.7	4.7	5
WAM 12.43, paratype	8.6	4.0	4.6	5
NMV P317782, paratype	8.5	3.6	4.2	5

ETYMOLOGY

Latin adjective. Notialis southern.

REMARKS

Specimens from Cape Le Grand are somewhat distorted and larger than the specimens from Walpole, but otherwise seem similar in morphology to the latter. This taxon is much smaller, has more convex whorls and fewer and fainter spiral lirae when compared to *Conorbis attractoides* (Tate, 1890) from the St Vincent and Otway Basins. The single specimen of *Conorbis* sp. from the late Eocene unnamed sandstone near Kalbarri figured by Darragh and Kendrick (2008, Figures 21–22) is much larger and relatively more slender than *C. notialis* sp. nov.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Family Drillidae Olsson, 1964

Genus *Splendrillia* Hedley, 1922

Splendrillia? sp.

Figures 9.19–20

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: 6 specimens (WAM 15.294–5; NMV P332365). Cape Le Grand National Park, old track surface, 3.7 km south-east of Frenchman Peak, 1 specimen (WAM 80.1345). Total 7 specimens.

DIMENSIONS

	Height	Width	No. of whorls
WAM 15.294	10.5	4.4	5

REMARKS

This species has some resemblance to *Splendrillia persica* (E.A. Smith, 1888), Indian Ocean, but the shoulder is not as prominent. It differs in the same way from *?Splendrillia* illustrated by Long (1981, plate 6, figure 4).

OCCURRENCE

Eucla Basin: Pallinup Formation.

Family Mangiliidae P. Fischer, 1883

Genus *Neoguraleus* Powell, 1939

Neoguraleus filiferus sp. nov.

Figures 9.5–7

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MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** WAM 12.46 from Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486.

Paratypes

WAM 12.47, NMV P316336 from type locality.

Other material

From type locality: WAM 67.145, 67.186, 69.189, 72.298, 04.176–7, 12.48–49; NMV P316334–5, P316337, P317784. Total 69 specimens.

DIAGNOSIS

Shell small with prominent shoulder and strong, sharp costae running from suture to suture, crossed by very fine spiral threads over whole whorl surface.

DESCRIPTION

Shell of small size for genus (up to 7 mm), elongate fusiform, with gradate spire of about four whorls, shoulder prominent. Protoconch of 1½ smooth whorls, the first whorl deviated slightly from axis of shell, merging gradually with teleoconch whorls. Axial sculpture of strong, sharp costae slightly narrower than interspaces, running from suture to suture, 10 per whorl. Spiral sculpture of close-set, very fine threads covering whole of whorl surface, about 20 on spire whorls and 40 plus on last whorl, extending onto canal. Aperture narrow, elongate, subeliptical, extending to short canal; very shallow posterior sinus scarcely visible.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 12.46, holotype	5.4	2.4	2.3	4
WAM 12.47, paratype	5.3	2.0	2.4	4
NMV P316336, paratype	4.7	2.2	2.1	4

ETYMOLOGY

Latin adjective. Filiferus bearing threads.

REMARKS

This species bears some resemblance to the type species, *Neoguraleus sinclairi* Gillies, Recent, New Zealand, but the whorls on *N.filiferus* sp. nov. are much more angular. It is very similar to specimens recorded from the Late Eocene Browns Creek Formation by Long (1981) as ?*Antiguraleus* sp. c. but has fewer and broader costae and a sharp rather than rounded shoulder. It is also much narrower. The genus is known from the Oligocene to Recent in New Zealand.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Family Pseudomelatomidae Morrison, 1966

Genus *Comitas* Finlay, 1926

Comitas silicicola sp. nov.

Figures 9.12–14

urn:lsid:zoobank.org:act:8D82A435-7C29-4406-8BB4-31217D53D8D0

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia*:** WAM 15.96 from Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486.

Paratypes

WAM 15.97, NMV P329321 from type locality.

Other material

From type locality: 22 specimens (WAM 15.95, 15.98; NMV P329320-23). Total 25 specimens.

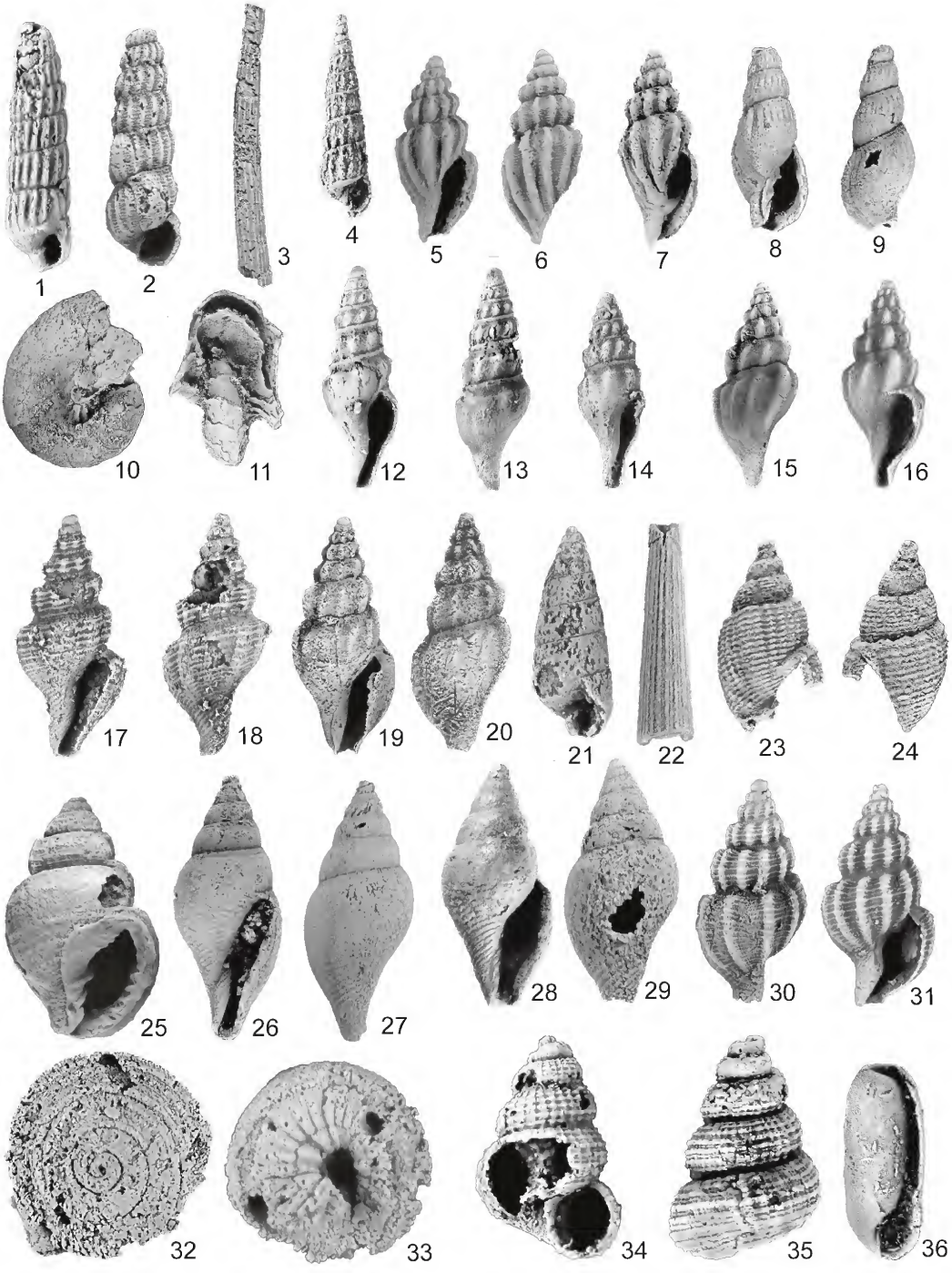
DIAGNOSIS

Shell small with prominent concave shoulder and broad costae running from shoulder to anterior suture, crossed by very fine spiral threads over the whole whorl surface.

DESCRIPTION

Shell of small size for genus (6–7 mm), elongate fusiform, spire of about five whorls, shoulder prominent. Protoconch of 1½ smooth whorls, the first whorl deviated slightly from axis of shell, merging abruptly with teleoconch whorls. Axial sculpture of strong, broad costae slightly narrower than interspaces running from shoulder to suture, six on last whorl, 9–11 on penultimate whorl, slightly weaker on last whorl and extending from shoulder to about mid whorl. Spiral sculpture of close-set, very fine threads covering whole

FIGURE 9 1, *Pyrgiscus* sp.: 1, WAM 69.194 (x 10);
2, 4, *Turbonilla* sp.: 2, WAM 15.87 (x 7); 4, WAM 15.88 (x 5);
3, 22, *Fissidentalium mawsoni* Ludbrook, 1956: 3, WAM 10.10 (x 3); 22, WAM 80.1357a (x 4);
5, 6, 7, *Neoguraleus filiferus* sp. nov.: 5, 6, WAM 12.46 (x 7) holotype; 7, WAM 12.47 (x 7) paratype;
8, 9, *Turehua* sp.: 8, 9, WAM 99.207 (x 5);
10, 11, *Eutrephoceras?* sp.: 10, 11, WAM 15.48 (x 2);
12, 13, 14, *Comitas silicicola* sp. nov.: 12, 13, WAM 15.96 (x 5) holotype; 14, WAM 15.97 (x 5) paratype;
15, 16, *Comitas?* sp.: 15, 16, WAM 15.296 (x 4);
17, 18, *Comitas aldingensis* Powell, 1944: 17, 18, WAM 67.166 (x 5);
19, 20, *Splendrillia?* sp.: 19, 20, WAM 15.294 (x 4);
21, *Syrnola* sp.: WAM 15.286 (x 7);
23, 24, *Semitriton* sp.: 23, 24, WAM 12.08 (x 4);
25, *Unitas* sp.: 25, WAM 05.176b (x 3);
26, 27, 28, 29, *Conorbis notialis* sp. nov.: 26, 27, WAM 67.167 (x 5) holotype; 28, 29, WAM 12.43 (x 5) paratype;
30, 31, *Asperdaphne* sp.: 30, 31, WAM 15. 289 (x 7);
32, 33, *Heliacus (Torinista) darraghi* Garrard, 1977: 32, 33, WAM 99.218 (x 10);
34, 35, *Tuba* sp.: 34, 35, WAM 15.49 (x 15);
36, *Cylichna* cf. *C. angusta* (Tate& Cossmann, 1897): WAM 12.47 (x 7).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of whorl surface, except shoulder, extending onto canal. Aperture narrow, elongate, subeliptical, extending into moderately short canal; very shallow posterior sinus scarcely visible on shoulder.

DIMENSIONS

	Height	Width	No. of whorls
WAM 15.96, holotype	7.8	2.5	5
WAM 15.97, paratype	6.9	2.4	5
NMV P329321, paratype	6.9	2.4	4

ETYMOLOGY

Latin noun in appostion. Silicicola inhabitant of sand.

REMARKS

This species bears some resemblance to *Comitas wynyardensis cudmorei* Long, 1918, Early Oligocene, Victoria, but has broader costae and a more concave shoulder. It differs from *Comitas aldingensis* Powell, 1944, Late Eocene, Blanche Point Formation, in having finer lirae and a more prominent shoulder.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Comitas aldingensis Powell, 1944

Figures 9.17–18

Comitas (Carinocomitas) aldingensis Powell, 1944: 18, plate 1, figure 7.

Comitas aldingensis Powell. Long, 1981: 22, plate 4, figures 2, 3.

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 67.166, 15.291–2; NMV P332361–3. Total 8 specimens.

DIMENSIONS

	Height	Width	No. of whorls
WAM 67.166	8.5	3.7	5

REMARKS

The carinae on the second protoconch whorl are very weak on Thomson Road specimens otherwise they closely match topotypes from Aldinga. Browns Creek specimens are somewhat midway between specimens from the previous localities, so the degree of development of the carinae seems to be rather variable.

OCCURRENCE

Eucla Basin: Pallinup Formation. **St Vincent Basin**: Blanche Point Formation (type). **Otway Basin**: Browns Creek Formation.

Comitas? sp

Figures 9.15–16

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486. WAM 15.296-8; NMV P332366. Total 8 specimens.

DIMENSIONS

	Height	Width	No. of whorls
WAM 15.296	8.6	3.2	5

REMARKS

All specimens are either broken or poorly preserved. This taxon does not seem to resemble any other from the Tertiary formations of Australia.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Family Raphitomidae Bellardi, 1875

Genus *Asperdaphne* Hedley, 1922

Asperdaphne sp.

Figures 9.30–31

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: WAM 15.289-290; P332360. Total 7 specimens.

DESCRIPTION

Shell fusiform of about 4 convex whorls and impressed sutures, last whorl contracting abruptly to anterior canal; small for genus (5.4–6 mm). Protoconch of about two whorls, sculptured with very fine, close-set lirae, merging abruptly into teleoconch whorls. Axial sculpture of well developed, erect costae, much narrower than interspaces, 11 on penultimate whorl, 10 on last whorl. Spiral sculpture of very thin lirae, much narrower than interspaces, nine on penultimate whorl, about 19 on last whorl extending onto canal. Aperture elongate oval with short anterior canal. Posterior sulcus against posterior suture, trace of sulcus forming band against suture sculptured with fine, close-set arcuate threads.

DIMENSIONS

	Height	Width	No. of whorls
WAM 15.289	5.6	2.8	4

REMARKS

This species is very similar to *Asperdaphne* sp .illustrated by Long (1981, plate 7, figure 8) from the late Eocene, Browns Creek Formation, but has more well defined costae.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Family Cancellariidae Forbes & Hanley, 1851

Genus *Turehua* Marwick, 1943

Turehua sp.

Figures 9.8–9

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: WAM 99.207, 15.14; P327566. Total 4 specimens.

DESCRIPTION

Shell small for genus (6.5–7.7 mm), narrow with convex whorls with impressed sutures. Spiral sculpture, worn, scarcely visible. Axial sculpture of thin, slightly opisthocline, non-collabral costae, slightly wider than interspaces, 28 on penultimate whorl. Whorls with a narrow posterior subsutural collar, weakly beaded where crossed by costae. Aperture elliptical; outer lip somewhat flared anteriorly, thickened externally into a weak varix. Columella overlaid with thick callus bearing three very prominent plaits; prominent anterior notch. Siphonal fasciole well developed.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 99.207	6.6	2.5	2.5	3+ specimen broken

REMARKS

All specimens are very worn and broken. There are no taxa in the fossil record in the Australian Tertiary that resemble this species. Species of the genus are known from the Eocene and Oligocene of Europe and from Eocene to Pliocene in New Zealand.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Genus *Semitriton* Cossmann, 1903

Semitriton sp.

Figures 9.23–24

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: WAM 12.08, 15.263; P329329. Total 4 specimens.

DIMENSIONS

	Height	Width	No. of whorls
WAM 12.08	8.5	4.5	4 shell distorted

REMARKS

This species is somewhat similar to *Semitriton varicosus* (Tate, 1888) from the Blanche Point Formation, but it is much narrower, has a caniculate suture and lacks the regular varices. In the latter respect it resembles the Victorian Oligocene species *S. dennanti* (Tate, 1898), but has a caniculate suture and is narrower. The species is much smaller than both the former species, but that may be because the four specimens are not mature individuals.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Genus *Unitas* Palmer, 1947

Unitas sp.

Figure 9.25

MATERIAL EXAMINED

Australia: ***Western Australia*:** Little Wharton Bay, near Mt Belcher, Duke of Orleans Bay: WAM 05.176b. Total 1 specimen.

DIMENSIONS

	Height	Width	Aperture height	No. of whorls
WAM 05.176b	14.4	9.2	6.0	4+

REMARKS

The single specimen is worn and broken. There is nothing like this taxon in the Eocene formations of eastern Australia.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Family Architectonicidae Gray, 1850

Genus *Heliacus* d'Orbigny, 1842

Subgenus *Torinista* Iredale, 1936

Heliacus (Torinista) darraghi Garrard, 1977?

Figures 9.32–33

?Heliacus (Torinista) darraghi Garrard, 1978: 550, Figure 10 (4–6).

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: (WAM 99.218). Total 1 specimen.

DIMENSIONS

	Width	Height	No. of whorls
WAM 99.218	3.76	1.8	3

REMARKS

The material consists of one tiny, juvenile specimen, the ventral side of which compares reasonably well with the smallest specimens of topotypes, though they are nearly twice its size. The dorsal surface is so poorly preserved that comparison is not possible. The ventral surface has a wide band around the umbilicus with coarse elongate nodules then a deep narrow groove, then a wide band of folds which fade about midway to periphery. It has a small subperipheral keel or rib and a rib right on periphery. In these respects it agrees closely with topotypes.

The species is rare in the Browns Creek Formation, but is more common at the type locality, Point Flinders.

OCCURRENCE

Eucla Basin: Pallinup Formation. **Otway Basin**: Browns Creek Formation; Glenaire Clay (type).

Family Mathildidae Dall, 1889

Genus *Tuba* Lea, 1833

Tuba sp.

Figures 9.34–35

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: WAM 15.49. Total 1 specimen.

DIMENSIONS

	Height	Width	No. of whorls
WAM 15.49	2.5	1.6	4+

REMARKS

The material consists of a single, small, broken specimen. The hypostrophic protoconch of this species strongly resembles that of *Tuba valkyrie* (Powell, 1971), Recent, New Zealand. The sculpture is more coarsely cancellate than the latter species. There is a species of *Tuba* in the Paleocene Pebble Point Formation, but this species has finer lirae and no obvious siphonal fasciole. *Tuba olsoni* (Maxwell, 1969), middle Eocene to early Miocene, New Zealand, has much stronger spiral lirae that are closer together than in this species.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Family Pyramidellidae Gray, 1840

Genus *Turbonilla* Risso, 1826

Turbonilla sp.

Figures 9.2, 9.4

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: 4 specimens (WAM 15.87–8; NMV P329312–3). Total 4 specimens.

DESCRIPTION

Shell elongate, of average size for genus (7.2 mm), whorls eight, convex, very weakly concave at posterior suture. Axial sculpture of sharp costae, much narrower than interspaces, 14–15 on last whorl. Spiral sculpture of very fine, close-set threads, about 20–22 on last whorl. Base with spiral sculpture only. Aperture oval.

DIMENSIONS

	Height	Width	No. of whorls
WAM 15.87	6.0	1.8	6+ specimen broken
WAM 15.88	7.1	1.7	8

REMARKS

All specimens are poorly preserved. The only complete specimen has eight whorls and a very poorly preserved heterostrophic protoconch.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Genus *Pyrgiscus* Philippi, 1841

Pyrgiscus sp.

Figure 9.1

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: WAM 69.194, 99.205; NMV P329311. Total 3 specimens.

DESCRIPTION

Shell attenuate, of at least seven whorls. Protoconch not preserved. Axial sculpture of broad costae about as wide as interspaces; last whorl with 17 costae. No trace of spiral sculpture preserved. Aperture ovate; columella with one weak plait at about midpoint.

DIMENSIONS

	Height	Width	No. of whorls
WAM 69.194	2.5	1.6	4+

REMARKS

All three specimens are poorly preserved and only one has the aperture present. This taxon bears some resemblance to *Pyrgiscus waihaoica* (Maxwell, 1992) from the Eocene of New Zealand.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Genus *Syrnola* A. Adams, 1860

Syrnola sp.

Figure 9.21

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: WAM 15.286; NMV P332357. Total 2 specimens.

DIMENSIONS

	Height	Width	No. of whorls
WAM 15.286	5.3	2.0	6

REMARKS

Both specimens are poorly preserved. Specimen P332357 consists only of the anterior two whorls of the teleoconch.

OCCURRENCE

Eucla Basin: Pallinup Formation

Family Cylichnidae H. & A. Adams, 1854

Genus *Cylichna* Lovén, 1846

Cylichna cf C. *angustata* (Tate & Cossmann, 1897)

Figure 9.36

c.f. *Bullinella angustata* Tate and Cossman, 1897: 11, pl. 1, figs 1–2.

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: 3 specimens WAM 15.47; NMV P329277, P329281. Total 3 specimens.

DIMENSIONS

	Height	Width
WAM 15.47	5.0	1.9

REMARKS

There are only three specimens in the entire collection, one well preserved and one consisting of about the top third of a complete specimen and the other broken and crushed. What little there is seems similar to Tate and Cossmann's specimens from the Kent Town Bore. No other opisthobranchs were found at the Thomson Road locality or elsewhere in the Pallinup Formation.

OCCURRENCE

Eucla Basin: Pallinup Formation. **St Vincent Basin**: Blanche Point Formation (type). **Otway Basin**: Browns Creek Formation.

Class Scaphopoda Bronn, 1862

Family Dentaliidae Children, 1834

Genus *Fissidentalium* Fischer, 1885

Fissidentalium mawsoni (Ludbrook, 1956)

Figures 9.3, 9.22

Dentalium (Fissidentalium) mawsoni Ludbrook, 1956: 2, plate 1, figures. 5, 6; Darragh and Kendrick, 2008, 228, Figures 3.1–2.

MATERIAL EXAMINED

Australia: ***Western Australia*:** Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: 8 specimens (WAM 10.10; 10.26, NMV P317170, P317188). Lucky Bay via Esperance, track surface 4.3 km south-east from Frenchman Peak, 0.1 km from road to Lucky Bay, Merivale 264386: 1 specimen (WAM 05.58). Cape Le Grand National Park, old track surface, 3.7 km south-east of Frenchman Peak: 4

specimens (WAM 80.1357. Cape Le Grand National Park, 0.8 km north-east of turn-off to Lucky Bay, Merivale 428219: 2 specimens (WAM 07.198). Total 15 specimens.

DESCRIPTION

Medium sized, robust, circular to slightly oval in cross-section, almost straight, curvature slight, where visible, tending toward apex. Ribs fine to very fine, of irregular size and spacing, numbering ca. 15–17 (apex) to ca 21–34 (aperture), increasing by intercalation. One specimen with apical slit preserved.

DIMENSIONS

	Length	Maximum diameter
WAM 80.1357a	9.8	2.4
WAM 10.10	16.0	1.9

REMARKS

This is a widely distributed and long-ranging dentaliid species from the Tertiary of southern and north-western Australia. Walpole specimens have been compared with topotypes from the middle Miocene Cadell Marl (Murray Basin) and with late Eocene material from the Browns Creek Formation (Otway Basin) and are closely comparable. Specimens are not as common in the Pallinup, Blanche Point and Browns Creek formations as they are in the unnamed sandstone of the Southern Carnarvon Basin and in younger formations of the Otway, Bass and Murray basins.

Specimens WAM 89.324 (Mt Barker) and WAM 66.1230 (SE of Kendenup) are similar to the large specimens of *Fissidentalium mawsoni* from Browns Creek.

OCCURRENCE

Southern Carnarvon Basin: unnamed sandstone. **Eucla Basin**: Pallinup Formation. **St Vincent Basin**: Blanche Point Formation; Dry Creek Sands. **Murray Basin**: Cadell Marl Member, Morgan Limestone (type). **Otway Basin**: Browns Creek Formation; Glen Aire Clay; Jan Juc Formation; Puebla Formation; Muddy Creek Formation; Fyansford Formation. **Bass Basin**: Freestone Cove Sandstone.

Class Cephalopoda Cuvier, 1795

Family Nautilidae Blainville, 1825

Genus *Eutrephoceras* Hyatt, 1894

Eutrephoceras? sp.

Figures 9.10–11

MATERIAL EXAMINED

Australia: *Western Australia*: Walpole, 24 km north of Walpole townsite on west side of Thomson Road, Deep River 743 486: (WAM 15.48) 1 specimen.

DIMENSIONS

	Maximum diameter	Maximum width
WAM 15.48	15.5	9.1

REMARKS

The unique specimen is a slightly crushed and broken juvenile. There are no saddles or lobes visible on the exposed septum, so a simple suture. The siphuncle is situated very close to the ventral margin. The cross section of the shell is somewhat narrow for typical species of *Eutrephoceras*, however, the other genera of nautiloids known from the Pallinup Formation include *Cimomia*, *Aturia* and *Teichertia*, all of which have a much more complicated suture than that present in this specimen. Darragh and Kendrick (2008) record juvenile specimens of a species of *Eutrephoceras* from the Late Eocene unnamed formation near Kalbarri in the Southern Carnarvon Basin, similar sized specimens of which seem much broader than the Thomson Road specimen, even allowing for the slight crushing of the latter, however, as there is only one poorly preserved specimen to compare, such a difference may not be real.

OCCURRENCE

Eucla Basin: Pallinup Formation.

Class Bivalvia Linnaeus 1758

Family Cardiidae Lamarck, 1809

Genus *Hedecardium* Marwick, 1944

Hedecardium moniletectum (Tate, 1887)

Figure 10

Cardium moniletectum Tate, 1887: 151, plate 14, figure 3a–b.

MATERIAL EXAMINED

Australia: *Western Australia*: Green Range, Plantagenet location 6475. WAM 76.06 1 specimen.

FIGURE 10 *Hedecardium moniletectum* (Tate, 1887): WAM 76.06 (x 2) Green Range, Plantagenet location 6475.

DIMENSIONS

	Length	Height
WAM 76.06	26.0	23.0

REMARKS

This specimen, a slightly distorted external mould, agrees fairly well with a specimen of this species from South Australia and matches Tate's figure.

OCCURRENCE

Eucla Basin: Pallinup Formation. **St Vincents Basin**: Blanche Point Formation (type).

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ADDENDUM

Whilst this paper was in final stages a further paper has been published on the sponge fauna of the Pallinup Formation:

Łukowiak, M. and Pisera, A. (2017). Bodily preserved Eocene non-lithistid demosponge fauna from southern Australia: taxonomy and affinities. *Journal of Systematic Palaeontology* **15**: 473–497.

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The Cardiidae (Mollusca: Bivalvia) of tropical northern Australia: A synthesis of taxonomy, biodiversity and biogeography with the description of four new species

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ABSTRACT — Cardiids or marine cockles are one of the best known families of marine bivalves in the world, with a long history of study and collection given their large and accessible shells, a tractable level of biodiversity globally (~290 species) and a solid fossil record extending to the late Triassic. In Western Australia, the cardiids are well known relative to other marine bivalve families, having been the subject of focussed treatment and consist of 31 species. However, given the proximity to the Indo-West Pacific, sheer size of the state and almost unparalleled number of habitats, the diversity is likely underestimated. Over the last 40 years, ongoing expedition work coupled with taxonomic study by the authors, has resulted in a doubling of the cardiid fauna of Western Australia (WA). Current cardiid diversity now stands at 68 species, including seven species of giant clams (Tridacninae). Subfamilial representation has changed little (except for the addition of Tridacninae previously in its own family, the Tridacnidae), and key genera in Cardiinae (e.g. *Fulvia*), Fraginae (e.g. *Fragum*) and Trachycardiinae (e.g. *Acrosterigma* and *Vasticardium*) still deliver much of the diversity. This updated biodiversity census has implications within and beyond Western Australia, with 16 new species records for the state and 14 new records for Australia, including four new species: *Acrosterigma extremattenuatum* sp. nov., *Ctenocardia pilbaraensis* sp. nov., *Microcardium scabrosum* sp. nov. and *Pratulum occidentale* sp. nov. Further taxonomic decisions include recognition of *Vasticardium serricostatum* (Melvill & Standen, 1899) and *Lunulicardia tumorifera* (Lamarck, 1819) as distinct species. *Vasticardium swanae* Maxwell, Congdon & Rymer, 2016 is considered a new synonym of *Cardium variegatum* G.B. Sowerby II, 1840; *Vasticardium lomboke* Vidal, 2003 is considered a new synonym of *Cardium mindanense* Reeve, 1844 and *Acrosterigma abrolhense* Vidal, 1999 is considered a new synonym of *Cardium cygnorum* Deshayes, 1855. All subspecies in the *Vasticardium elongatum* (Bruguière, 1789) complex are raised to species level.

New acquisitions arising from tropical survey work in the north have yielded all of the newly added species and all newly described species in the Western Australian Museum (WAM) cardiid collections. This is in contrast to the relatively stable biodiversity of southwestern Western Australia. In the north, diversity is highly structured with sixteen taxa found restricted to offshore islands and shoals (e.g. *Vasticardium philippinense* (Hedley, 1899), *V. elongatum* (Bruguière, 1789), *Corculum cardissa* (Linnaeus, 1758), *Ctenocardia fornicata* (G.B. Sowerby II, 1840), *C. gustavi* Vidal & Kirkendale, 2007), and a smaller cohort found exclusively inshore (e.g. *A. extremattenuatum* sp. nov., *V. wilsoni* (Voskuil & Onverwagt, 1991), *C. pilbaraensis* sp. nov.). Biodiversity comparisons are made with other tropical states in northern Australia, including the Northern Territory (NT) and Queensland (Qld), and considered together these records support recognition of a vast Dampierian Province. Regional biogegraphic comparisons are also made to examine whether cardiids in northern Australia are as diverse as other central Indo West Pacific (IWP) areas. To improve management of the commercially important Tridacninae (giant clams), we provide the first formal records of species diversity and distribution in this group for WA. While cardiids are relatively well characterised, persistent gaps remain that are not unique to this family. Our knowledge of small and/or cryptic species, as well as the deep water fauna broadly, lags behind our understanding of shallow water macromolluscs.

KEYWORDS: Indo-West Pacific, Western Australia, Northern Territory, distributions, endemism, survey, cockles, giant clams

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IN MEMORY OF BARRY WILSON (1935–2017)

'Probably most of the common and conspicuous shells, those which first attract attention, are here represented. But this number will be increased perhaps fourfold when small species and those from deep water are collected.'

(Hedley 1916: 152)

INTRODUCTION

BACKGROUND

In their revision of the Cardiidae of Western Australia, Wilson and Stevenson (1977) reported and described 31 species from the WA coast (Tridacninae excluded), four of which were described and named as new (Table 1). This often cited regional monograph provided taxonomists with a wealth of information; by drawing attention to deficiencies in the generic nomenclature, it formed a valuable benchmark for subsequent malacologists dealing with this family. This work also integrated specimens from a number of important surveys in WA including; (1) the early work of Sir Joseph Verco on the deep shelf benthic molluscs of the Southern Australian Realm, including sites off the southern coast of WA, (2) the Western Australian Museum dredging expeditions (1965 onwards) on the north west and west coasts, viz: Hawaiian WA Expedition on 'Davena', 'Bluefin' and other chartered commercial trawlers, (3) the two West Coast outer shelf surveys aboard the Royal Australian Navy (RAN) frigates 'Diamantina' and 'Gascoyne' converted for service in the national oceanographic program; (4) collaboration on a number of occasions with CSIRO on oceanographic cruises, as well as (5) the targeted onshore surveys of molluscan faunas in Cockburn Sound, the Houtman Abrolhos Islands, Shark Bay, Ningaloo Reef, Barrow Island and the Dampier Archipelago.

Since this work focussed in WA, cardiids have received ongoing global attention, including a fully annotated and illustrated bibliography of living and fossil species (Hylleberg 2004), reviews at generic and subfamilial levels (ter Poorten 2005, 2013, Vidal 1994, 1999), regional monographs (ter Poorten 2009), phylogenetic study (Schneider and Ó Foighil 1999, Kirkendale 2009, Herrera et al. 2015) and the recognition of new species (e.g. ter Poorten 2009, 2015, Poutiers 1981, 2006, Su et al. 2014, Monsecour 2016). Not only has our knowledge of cardiid biodiversity, relationships and distributions improved, but the amount of material available for study has also increased, owing to numerous expeditions conducted by several museums and institutions (see 'Abbreviations' for museum and institutional material incorporated in this study). Much of this collecting has focussed on the highly diverse Indo-West Pacific, including the northern coast of WA. The incorporation of a greater diversity of sampling methods on many of these expeditions has contributed to improved taxonomic coverage in previously neglected habitats.

WESTERN AUSTRALIA WITHIN A BROADER BIOGEOGRAPHICAL SETTING

At the largest scale are the marine biogeographic zones, which are largely structured by temperature (e.g. tropical, warm temperate, cold temperate and cold) (e.g. Briggs and Bowen 2012). These have remained relatively stable through time (e.g. compare Ekman 1956, Briggs 1974, Harzhauser et al. 2002, with Briggs and Bowen 2012 and Wilson 2013). Within these zones, biogeographic regions (Briggs 1974) can be further delineated, and the recognition of divisions, but also connectivity, among ocean basins is an important consideration at this scale (e.g. 14 shelf regions and provinces outlined by Briggs and Bowen 2012, these roughly correspond to the realms of Harzhauser et al. 2002, as followed by Wilson 2013). Below these two higher order biogeographic levels (of zone and region), the introduction of new methods and/or improved datasets, are altering traditional world views.

Provinces have been used to denote areas of physical and faunal distinction with 10% endemism, a pervasive metric that is followed here (Briggs and Bowen 2012, Wilson 2013). Integration of recent research, such as phylogeography, has provided new data of relevance to assessing species richness and endemicity for coral reef fish, which has in turn altered delineation of provinces in some biogeographic studies (e.g. globally: Briggs and Bowen 2012, Kulbicki et al. 2013; south Australia: Waters et al. 2010). Below the provincial level, two works are of recent significance and these are the global ecoregion classification system (Spalding et al. 2007) and in Australia, the IMCRA system of bioregions (e.g. IMCRA, Thackway and Cresswell 1998).

In WA, two distinct regions are widely recognised. These are the Southern Australian and Northern Australian regions of Wilson (2013), with the Western Overlap Zone off Geraldton/Houtman Abrolhos Islands separating the two. The south is predominantly a

temperate fauna, while the north is largely a tropical fauna. These regions correspond to Briggs and Bowen's (2012) Western Pacific region in the south and tropical IWP region in the north (see discussion below for conflicts).

Within the Southern Australian region, Wilson (2013) recognises two distinct provinces, a Southwestern Province and a Southeastern Province (Wilson 2013: 9, Fig. 1.3). The break between these two areas is not well specified by Wilson and Gillett (1971: 17–18) and no strict endemism criteria (e.g. 10% threshold) are discussed. These boundaries instead are based on expert knowledge of regional faunal diversity and distribution, as well as historical concepts delineated by others, notably and of relevance to the southwest of WA, is the Flindersian of Whitley (1932) (previously the Adelaidean of Hedley (1904, 1926)). The Flindersian Province extends from southwestern WA, across South Australia and to the western edge of Victoria. The Flindersian Province abuts: 1) the Maugean to the south (including Tasmania) and 2) along the continent, the Peronian (that subsumes all of New South Wales (NSW)). Waters et al. (2010) utilised an extensive dataset on marine algae to quantitatively test southern Australian provincial boundaries and found support for Flindersian, Peronian and Maugean Provinces, refining extension of the Maugean to southern NSW, with a slight shift in the boundary of the Maugean-Flindersian in Western Victoria. Within the Western Pacific region of Briggs and Bowen (2012) five provinces are differentiated, and consistent with others, is the recognition of a Warm Temperate Province in southwestern Australia. This is the only province discussed in the Western Pacific region that is not technically in the Western Pacific ocean, but in the Indian Ocean. The warm temperate province in southwestern Australia recognised by Briggs and Bowen (2012) aligns closely with the Southwestern Province of Wilson (2013).

To the north, WA is part of the tropical IWP region. The tropical IWP region or realm has long been recognised as the largest and richest marine biogeographic region in the world, extending from Africa in the Indian Ocean across to Easter Island in the Central Pacific Ocean (Forbes 1856, Ekman 1956, Briggs 1974, Spalding et al. 2007, Briggs and Bowen 2012, Wilson 2013). The pinnacle of marine diversity, the central IWP (also known as the Indo-Malay Archipelago, East Indies Triangle or Coral Triangle), bordered by the Philippines, Indonesia, Papua New Guinea and the Solomon Islands, lies in the centre of this region (Veron et al. 2009, 2015). Surveys over the last several decades have added greatly to improving the biodiversity estimates here (i.e. Bouchet 2009, ter Poorten 2009), which in turn allow improved faunal comparison with neighboring areas.

Wilson (2013) outlines a Northern Australian region and recognises two distinct provinces, a Northwestern Province and a Northeastern Province (Wilson 2013: 9, Fig. 1.3). Distinction at the provincial level in the north was historically recognised and is supported by Wilson (2013: 9–10). For example, Whitley (1932) outlined four provinces: 1) Dampierian Province (Hedley 1926) extending from Shark Bay (WA) to the Gulf of Carpentaria (Qld); 2) the Solanderian Province that incorporates the Great Barrier Reef and extends from the Gulf of Carpentaria (Qld) to approximately Gladstone (Qld); 3) the Banksian (coastal Qld) and 4) the Phillipian (Norfolk and Lord Howe Islands). Surprisingly, Wilson and Stevenson (1977) argued against recognition of a distinct Dampierian Province, even though cardiid species counts indicated 15% endemism (4/27 endemics). While these classic subdivisions are moderately different to Wilson (2013: 9–10), they contrast even more significantly with Briggs and Bowen (2012).

Revisiting the concept of a Dampierian Province is relevant to this study given the application of cardiid data to retesting its efficacy (Wilson 2013: 9–10), but also the dominant role that WA plays in the tropical north. Within WA, this tropical province includes an enormous diversity of habitats, geology and history under the sway of a wide range of often seasonal oceanographic influences. Notable areas within this large province include the wide continental mid-shelf area referred to as the North West Shelf (Rowley Shelf to the south and Sahul Shelf to the north), numerous offshore or oceanic islands, shoals and atolls to the west of the shelf, inshore areas of the coastal Kimberley, Canning and Pilbara as well as important features of the southern boundary of the province, including Shark Bay and adjacent Ningaloo and Exmouth Gulf, and the Northwest Cape area (Wilson 2013). The Dampierian Province comprises five ecoregions in WA (Spalding et al. 2007: 210, 145, 144, 141 and 140) and 27 IMCRA bioregions (Integrated Marine and Coastal Regionalisation for Australia) (Thackway and Cresswell 1998) (see Wilson 2013: 10, fig. 1.5; Figure 1). Within this area two major distinctions are considered that are best highlighted using IMCRA bioregions: the inner or coastal continental zone of WA (Bioregions NIN, PIO, PIN, NWS, EMB, CAN, KSD, KIM, BON, CAB), and the outer or offshore oceanic shelf of WA (Bioregion OSS) (Figure 1). To place in perspective the scale and complexity of these regions, the IMCRA bioregion NWS refers to the North West Shelf, a large area of continental shelf that is itself the subject of an entire book (Wilson 2013).

Southwestern WA has historically been considered part of the Flindersian Province (Adelaidean of Hedley 1926), a large province that extends from Perth to western Victoria (Wilson 2013, Waters et al. 2010, Colgan 2015). The south coast of Australia broadly has

an exceptionally high level of molluscan endemism estimated as 75% (Huber 2010) or even up to 95% (Wilson and Allen 1987, Ponder et al. 2002). In WA, this region begins approximately at Shark Bay and extends south, encountering the cold Southern ocean across the Great Australian Bight to the border with South Australia. This area is comprised of five ecoregions (Spalding et al. 2007: 211, 209, 208, 207, 206) and 12 bioregions as defined by IMCRA (Thackway and Cresswell 1998, Figure 1: ABR, CWC, LNE, WSC, EUC, MUR, EYR, SG, NSG, SVG, COR, OTW). The area between Shark Bay and Cape Naturaliste or Cape Leeuwin, mentioned in the preceding paragraph, is regarded as the Western Overlap Zone (Wilson 2013: 9, Fig. 1.3). This small transitional area is comprised of two ecoregions (Spalding et al. 2007: 211 and northern part of 209) and five bioregions as defined by IMCRA (Thackway and Cresswell 1998, Figure 1).

ABIOTIC FORCES AND BIOTIC IMPLICATIONS

This paper with a focus on cardiid taxonomy is not a comprehensive treatment of earth history and related topics in WA. For this, we refer the reader to Wilson (2013) (and references therein).

The latitudinal diversity gradient is strong in WA with higher diversity in the tropical northern fauna and a comparatively depauperate fauna in the south. While the tropical northern fauna is shared with much of the IWP, the south has a much higher degree of endemism. Factors responsible for this pattern are complex but include geology and oceanography through time. Major geological events have significantly altered the landscape of WA in the distant past (the Cenozoic, the last 66 million years) with a prolonged sequence of tectonic and sedimentary events, followed by sea level changes in the recent past especially in the Quaternary (the last 2.6 million years). These events have created the diverse coastline of WA, from the deep sea trenches of Perth canyon in the southwest to, for example, the two significant geological features of the north (Kimberley Basin and Pilbara Craton) (Wilson 2013). More recently, sea level transgressions and regressions have made available differing amounts of habitat for marine biota that not only influence ecological communities but also regulate connectivity of marine populations through time.

Oceanographic effects via current systems also serve to move propagules along the extensive and north-south oriented coastline (motile adults and also planktotrophic larvae) and thus influence connectivity. Significantly, the coast of WA is influenced by a southward flowing warm offshore current, known as the Leeuwin Current (Wilson and Kirkendale 2016). Southward penetration of this current is annually variable, but when strong can carry larvae and thus taxa from more northerly waters southward (via the Indonesian Through Flow or ITF that then connects with the Holloway and Leeuwin currents in WA). This can extend penetration of the northern IWP fauna along the WA coast seasonally (Wilson and Allen 1987, Richards et al. 2016, Wilson 2016).

Major drainages of coastal river systems along the WA mainland as well as massive tidal cycles contribute and/or resuspend significant amounts of sediment. This resource can sustain feeding planktotrophic larvae and filter feeders but also inhibit settlement of certain molluscs. Offshore there exist an array of shoals, islands and atolls and as some of these geological features do not exist near shore, they offer unique habitats. Moreover, environmental conditions differ significantly between inshore and offshore settings. Large river systems in the Kimberley, for example, the Fitzroy River (Mardoowarra) generate large amounts of seasonal runoff that result in low turbidity and eutrophic (high nutrient) conditions. This is in contrast to offshore settings where the absence of large river systems precludes high levels of runoff, resulting in clear waters and oligotrophic (low nutrient) seas (e.g. Rowley Shoals). However, similar conditions between onshore and offshore can occur where coastal islands in nearshore habitats are distant from the mainland and therefore removed from the influences of large rivers (e.g. western coast of Barrow Island) or where the continental shelf is narrow and deep water flushes nearshore habitats (e.g. Ningaloo Reef) (Wilson 2013).

Together factors of geology, geography and oceanography have shaped marine faunal biodiversity of WA. As mentioned above, the most marked contrast is a latitudinal gradient with high biodiversity of the tropical northern marine fauna (both offshore and coastal bioregions) compared to that of the warm temperate fauna of the south. The gradual shift and decline of the former southwards within the transition zone, and the converse decline of the warm temperate fauna northwards is apparent across faunal groups.

AIMS

The main impetus for this project was to improve the taxonomic understanding of cardiids in WA by augmenting the seminal work of Wilson and Stevenson (1977) with the integration of WAM cardiid collections made in the ensuing 40 years. To complete this task required revisiting the collections to improve identifications and clarify species boundaries with the addition of new distributional records, registration of important legacy material, description of new species and updates to nomenclature. The significance of the north to increasing the biodiversity knowledge of WA, led to consideration of cardiid collections from other tropical areas in Australia, including the Northern Territory and to a lesser extent Queensland. This facilitated extension of the study area to the Northwestern Province, roughly coinciding with the Dampierian Province as outlined by Wilson (2013)

and earlier workers (striped area in Figure 1). An important goal of this study was to apply the newly considered cardiid source dataset to test for support of the Dampierian Province (e.g. provisional conclusion of Wilson (2013: 392–393)). Considered together these data provide the most accurate assessment of cardiids to be developed for WA and Australia, and when considered in partnership with other survey data, such as that made possible by recent MNHN (Paris Museum) efforts, the Central IWP region. This is a rare event; very few invertebrate groups have had this level of recent attention at this scale.

FIGURE 1 Map of north-western Australia showing the main reefs, islands and places referred to in this study. The continental zone (< 200 m isobath, the shelf edge) is denoted by the lightest blue. Red-brown arrows indicate main oceanic current systems (after Hoeksema 2007; Wilson 2013, 2014). ITF = Indonesian Throughflow. Striped area indicates the primary studied area. Green lines indicate the borders of the IMCRA coastal mesoscale bioregions of Western Australia: TS = Torres Strait, WCY = West Cape York, KAN = Karumba-Nassau, CAR = Carpentaria, WLY = Wellesley, PEL = Pellew, GRO = Groote, AWS = Arnhem Wessel, ARA = Arafura, COB = Cobourg, VDG = Van Diemens Gulf, TWI = Tiwi, ANB = Anson Beagle, CAB = Cambridge-Bonaparte, BON = Bonaparte Gulf, CAB = Cambridge-Bonaparte, OSS = Oceanic Shoals, KIM = Kimberley, KS = King Sound, CAN = Canning, NWS = North West Shelf, EMS = Eighty Mile Beach, PIO = Pilbara Offshore, PIN = Pilbara Nearshore, NIN = Ningaloo, ZUY = Zuytdorp, SBY = Shark Bay, ABR = Houtman Abrolhos Islands, CWC = Central West Coast. Beyond the southern limit of the primary studied area, other WA bioregions are: LNE = Leeuwin-Naturaliste, WSC = Western Australia South Coast, EUC = Eucla (after Thackway and Cresswell 1998).

TABLE 1 Cardiidae of Western Australia as treated by Wilson and Stevenson (1977) and their valid name according to current classification. Source: WoRMS (2017), supplemented with unpublished data from the authors.

Wilson and Stevenson (1977) name	Currently accepted valid name	WA material to be assigned to
Ctenocardia perornata (Iredale, 1929)	= *Ctenocardia virgo* (Reeve, 1845)	*Ctenocardia virgo* (Reeve, 1845)
Ctenocardia fornicata (Sowerby, 1841)	*Ctenocardia fornicata* (G.B. Sowerby II, 1840)	*Ctenocardia pilbaraensis* sp. nov.
Lyrocardium lyratum (Sowerby, 1841)	*Lyrocardium lyratum* (G.B. Sowerby II, 1840)	*Lyrocardium lyratum* (G.B. Sowerby II, 1840)
Fragum (*Fragum*) *fragum* (Linnaeus, 1758)	*Fragum fragum* (Linnaeus, 1758)	*Fragum fragum* (Linnaeus, 1758)
Fragum (*Fragum*) *unedo* (Linnaeus, 1758)	*Fragum unedo* (Linnaeus, 1758)	*Fragum unedo* (Linnaeus, 1758)
Fragum (*Lunulicardia*) *retusum* (Linnaeus, 1767)	*Lunulicardia retusa* (Linnaeus, 1767)	*Lunulicardia retusa* (Linnaeus, 1767)
Fragum (*Lunulicardia*) *hemicardium* (Linnaeus, 1758)	*Lunulicardia hemicardium* (Linnaeus, 1758)	*Lunulicardia tumorifera* (Lamarck, 1819)
Fragum (*Afrocardium*) *erugatum* (Tate, 1889)	*Microfragum erugatum* (Tate, 1889)	*Fragum erugatum* (Tate, 1889)
Fulvia aperta (Bruguière, 1789)	*Fulvia aperta* (Bruguière, 1789)	*Fulvia aperta* (Bruguière, 1789)
Fulvia tenuicostata (Lamarck, 1819)	*Fulvia tenuicostata* (Lamarck, 1819)	*Fulvia tenuicostata* (Lamarck, 1819)
Laevicardium attenuatum (Sowerby, 1841)	*Acrosterigma attenuatum* (G.B. Sowerby II, 1841)	*Acrosterigma extremattenuatum* sp. nov.
Laevicardium biradiatum (Bruguière, 1789)	*Acrosterigma biradiatum* (Bruguière, 1789)	*Acrosterigma biradiatum* (Bruguière, 1789)
Acrosterigma elongatum (Bruguière, 1789)	*Vasticardium elongatum* (Bruguière, 1789)	*Vasticardium wilsoni* (Voskuil & Onverwagt, 1991)
Acrosterigma reeveanum (Dunker, 1852)	= *Vasticardium vertebratum* (Jonas, 1844)	*Vasticardium vertebratum* (Jonas, 1844)
Acrosterigma alternatum (Sowerby, 1841)	= *Vasticardium angulatum* (Lamarck, 1819)	*Vasticardium angulatum* (Lamarck, 1819)
Acrosterigma dupuchense (Reeve, 1845)	*Vasticardium dupuchense* (Reeve, 1845)	*Vasticardium dupuchense* (Reeve, 1845)
Acrosterigma fultoni (Sowerby, G.B., 1916)	*Vasticardium fultoni* (G.B. Sowerby III, 1916)	*Vasticardium fultoni* (G.B. Sowerby III, 1916)
Acrosterigma cygnorum (Deshayes, 1855)	*Acrosterigma cygnorum* (Deshayes, 1855)	*Acrosterigma cygnorum* (Deshayes, 1855)
Acrosterigma dampierense Wilson & Stevenson, 1977	= *Acrosterigma impolitum* (G.B. Sowerby II, 1834)	*Acrosterigma impolitum* (G.B. Sowerby II, 1834)
Acrosterigma transcendens (Melvill & Standen, 1899)	*Acrosterigma transcendens* (Melvill & Standen, 1899)	*Acrosterigma transcendens* (Melvill & Standen, 1899)
Acrosterigma marielae Wilson & Stevenson, 1977	*Acrosterigma marielae* Wilson & Stevenson, 1977	*Acrosterigma marielae* Wilson & Stevenson, 1977
Acrosterigma vlamingi Wilson & Stevenson, 1977	= *Acrosterigma impolitum* (G.B. Sowerby II, 1834)	*Acrosterigma impolitum* (G.B. Sowerby II, 1834)
Acrosterigma rosemariensis Wilson & Stevenson, 1977	= *Acrosterigma impolitum* (G.B. Sowerby II, 1834)	*Acrosterigma impolitum* (G.B. Sowerby II, 1834)
Nemocardium (*Nemocardium*) *bechei* (Reeve, 1840)	*Nemocardium bechei* (Reeve, 1847)	*Nemocardium probatum* (Iredale, 1927)
Nemocardium (*Microcardium*) *torresi* (Smith, 1885)	*Frigidocardium torresi* (E.A. Smith, 1885)	*Frigidocardium eos* (Kuroda, 1929) or *Frigidocardium helios* ter Poorten & Poutiers, 2009
Nemocardium (*Microcardium*) *exasperatum* (Sowerby, 1885)	*Frigidocardium exasperatum* (G.B. Sowerby II, 1839)	*Frigidocardium eos* (Kuroda, 1929) or *Frigidocardium iris* Huber & ter Poorten, 2007
Nemocardium (*Pratulum*) *thetidis* (Hedley, 1902)	*Pratulum thetidis* (Hedley, 1902)	*Pratulum occidentale* sp. nov. or *Pratulum thetidis* (Hedley, 1902)
Plagiocardium (*Maoricardium*) *setosum* (Redfield, 1848)	*Maoricardium setosum* (Redfield, 1848)	*Maoricardium setosum* (Redfield, 1848)
Plagiocardium (*Maoricardium*) *frazeri* (Garrard, 1963)	*Maoricardium fraseri* (Garrard, 1963)	*Maoricardium fraseri* (Garrard, 1963)
Vepricardium multispinosum (Sowerby, 1838)	*Vepricardium multispinosum* (G.B. Sowerby II, 1839)	*Vepricardium multispinosum* (G.B. Sowerby II, 1839)
'*Cardium*' *victor* Angas, 1872	*Freneixicardia victor* (Angas, 1872)	*Freneixicardia victor* (Angas, 1872)

MATERIAL AND METHODS

The material used in this study largely originates from study of the WAM collections over 10 years. Supplementary sources are other public collections, the reference collection of the first author, other private collections and literature records. Altogether, 1,874 WA Cardiidae samples were examined and verified. Occasional literature records are included that refer to tropical northern Australia and relate to the first recordings for the study area or add to our understanding of the distributions. For comparisons with the diversity of other Australian states and Central IWP areas (Northern Territory (hereafter abbreviated as NT), Queensland (hereafter abbreviated as QLD), Indonesia, Philippines, Papua New Guinea and the Solomon Islands) over 7,400 Cardiidae samples have been examined, identified and documented. To facilitate cross-reference, former WAM registration numbers used by Wilson and Stevenson (1977) are provided in brackets.

The study area for the taxonomomic section initially followed the political boundaries of WA following Wilson and Stevenson (1977): the continental coastal waters of WA and the oceanic emergent reefs of the adjacent shelf margin. Two extremely remote Australian Exclusive Economic Zone (EEZ) areas are excluded: Cocos (Keeling) Islands and Christmas Island, as these are located more than 1,400 km off the main continent and were not included by Wilson and Stevenson (1977). However, an overview of the cardiid fauna of these latter islands, nearly all of which also occur on the Australian North West Shelf, is given in the Results section. In order to obtain a more complete understanding of the cardiid fauna of tropical northern Australia, the study area includes the Houtman Abrolhos Islands in the south and the NT and the Gulf of Carpentaria in the north east. All newly recorded species (i.e. not covered by Wilson and Stevenson (1977) originate from the tropical part of WA. An overview of the WA cardiid fauna, allowing for direct comparisons with Wilson and Stevenson (1977), is given in the Results section.

For the biodiversity and biogeographical comparisons in the Results section, the scope has been further enlarged, covering the Central IWP and Australia as outlined in Figure 25.

Western Australian species reviewed in this study are limited to those not covered by Wilson and Stevenson (1977); the latter are listed in Table 1 and commented on thereafter. Furthermore, The North/East and South/East endpoints of species ranges of all WA cardiids as currently defined, based on all verified material, are given in the Results section. Nearly all included species have recently been treated and figured by ter Poorten (2009, 2011) and Huber (2010), hence these works are included where appropriate. Apart from Wilson and Stevenson (1977), Australian literature is limited to the wellknown publications of Lamprell and Whitehead (1992) and Lamprell and Healy (1998). Systematics at subfamily level follow the most recent assessment of cardiid relationships based on molecular phylogeny (Herrera et al. 2015) with genera and species placed in alphabetical order. Lists of material examined are organised geographically north to south and east to west. NW Australian distribution maps are provided for all species not treated by Wilson and Stevenson (1977) for which at least three records could be established (Figures 17–20). Records based on dead-collected material (a category that includes single long dead valves but not subfossils, as well as recently dead paired valves with the ligament intact) are indicated by a black circle, while live records (based on live-collected material) are indicated by a white circle, to provide transparency in distributional and species occurrence data. Given sizes refer to adult specimens, followed after the dash by the maximum observed size (not necessarily of Australian origin).

ABBREVIATIONS

Acronyms of institutions and repositories

AIMS	Australian Institute of Marine Science, Townsville, Australia
ALA	Atlas of Living Australia, http://ala.org.au
AMS	Australian Museum, Sydney, Australia
ANSP	Academy of Natural Sciences, Philadelphia, United States
CSIRO	Commonwealth Scientific and Industrial Research Organisation, Canberra, Australia
MNHN	Muséum national d'Histoire naturelle, Paris, France
NHMUK	Natural History Museum, London, United Kingdom
NMW	National Museum of Wales, Cardiff, United Kingdom
NTM	Museum and Art Gallery of the Northern Territory, Darwin, Australia
NMR	Natuurhistorisch Museum Rotterdam, Netherlands
OZCAM	Online Zoological Collections of Australian Museums, http://ozcam.org.au
QM	Queensland Museum, South Brisbane, Australia
RMNH	Naturalis Biodiversity Center, Leiden, Netherlands.
TP	Colln J.J. ter Poorten, Hilversum, Netherlands
UF	Florida Museum of Natural History, University of Florida, United States
WAM	Western Australian Museum, Welshpool, Australia
ZMA	Zoological Museum Amsterdam, Netherlands (now incorporated in Naturalis Biodiversity Center, Leiden, Netherlands)

Other abbreviations

A, found alive; colln, collection; Exped., Expedition; fragm., fragment(s); FRV, Fisheries Research Vessel; FV, Fisheries Vessel; H, height; L, length; l.v., left valve; MV, Motor Vessel; n.o.r., northern offshore reefs; p.v., paired valves; RV, Research Vessel; r.v., right valve; s.v., single valve(s).

TAXONOMY

PRIOR WORK

In order to align our work with that of Wilson and Stevenson (1977), the key point of reference for the present study, the currently accepted name and the current identification for each species treated is listed in Table 1. Additional comments on taxa presented in Wilson and Stevenson (1977) immediately follow.

Comments on Wilson and Stevenson (1977) taxa (Table 1)

***Ctenocardia fornicata* (Sowerby, 1841)**

All Wilson and Stevenson (1977) records refer to *Ctenocardia pilbaraensis* sp. nov.; true *Ctenocardia fornicata* (G.B. Sowerby II, 1840) is known from the outer shelf of WA based on a single record (see under that species).

***Fragum* (*Lunulicardia*) *hemicardium* (Linnaeus, 1758)**

Extensive collection research indicates that the WA population of *Lunulicardia hemicardium* (Linnaeus, 1758) is limited to a small area ranging from Shark Bay to Exmouth Gulf. This species is neither recorded from the North West Shelf, nor from the Timor Sea, NT or the Gulf of Carpentaria (NT, QLD), and is thus fully separated from its main Central IWP distribution (e.g. QLD). Given its relatively large size and common shallow water occurrence, this distribution is unlikely to have arisen as a sampling artefact, especially considering that the conspecific, *L. retusa*, has a wide distribution, well documented in WAM collections. This seems an example of allopatric speciation, in need of specific separation, for which the name *Cardium tumoriferum* Lamarck, 1819 is available. Provisionally, the latter name is employed for WA material that differs by the following characters: antero-dorsal area flattened, lacking radial ribs; rib sculpture on median part consisting of scales rather than tear drop-like papillae; posterior part only slightly protruding and maximum size larger (H up to 73 mm). This group is currently under study by the second author.

***Fragum erugatum* (Tate, 1889)**

This species has been placed in five different genera (Hylleberg 2004: 502) given the high variability in characters of shape, hinge and dentition, for example, evident in specimens from the hypersaline environment of Shark Bay, WA. Wilson and Stevenson (1977) placed *erugatum* in the genus (and subgenus) *Fragum* (*Afrocardium*). Later, Schneider (1998) moved *erugatum,* on the basis of several characters, to *Microfragum*. More recently, ter Poorten (e.g. 2009) followed Schneider (1998) in this placement, however, Morton (2000) and Vidal (2001) did not. Kirkendale (2009) recovered *erugatum* firmly at the base of the paraphyletic genus *Fragum* and sister to *F. sueziense*. Examination of external shell features corroborate placement of *erugatum* in the genus *Fragum*, given the beading sculpture aligned with other members of the genus *Fragum* and not deciduous scales, as found in both representatives of the genus *Microfragum* (*M. festivum,* type species of the genus, but also *M. subfestivum*). This species is photosymbiotic as are all known members of the genus *Fragum*, along with the two other wholly photosymbiotic genera, *Lunulicardia* and *Corculum*. No species of *Microfragum* have been found to possess symbionts. Characters including gross shell shape, hinge and dentition may be homoplasious and not reliable indicators of phylogenetic relationship for specimens of *erugatum* from extreme environments. We suggest *erugatum* be moved from the genus *Microfragum* and placed in the genus *Fragum*.

***Fulvia aperta* (Bruguière, 1789)**

Recorded as far south as Geographe Bay by Wilson and Stevenson (1977). All examined records of *F. aperta* south of Point Cloates proved to belong to a different species, *F. tenuicostata* (Lamarck, 1819). Compared to material from QLD and Indonesia, the shell exterior of WA populations is covered with dense granulations for a greater shell portion (two-thirds), the lunule is tinged with purple and the shell attains larger dimensions (L up to 57 mm, ZMA. MOLL.206088). This species is currently under study by the first author.

***Laevicardium attenuatum* (Sowerby, 1841)**

True *Acrosterigma attenuatum* (G.B. Sowerby II, 1841) does not occur in WA or the NT. In WA it is replaced by the endemic *A. extremattenuatum* sp. nov. (treated here). Generic placement follows Vidal (1999) with DNA analysis (Herrera et al. 2015) supporting this taxonomic distinction.

***Acrosterigma elongatum* (Bruguière, 1789)**

Nearshore WA specimens are exclusively in agreement with *Vasticardium wilsoni* (Voskuil & Onverwagt, 1991), relegated by Vidal (1993) to a subspecies of *Cardium elongatum* Bruguière, 1789. See systematic section for treatment of this species and generic assignment.

***Acrosterigma fultoni* (Sowerby, G.B., 1916)**

Vidal (1997: 251) applied the name *Cardium ornatum* G.B. Sowerby III, 1877 for this species that is a junior homonym of *Cardium ornatum* d'Orbigny, 1850 and *Cardium ornatum* Eichwald, 1855. The next available name is *Cardium fultoni* G.B. Sowerby III, 1916.

***Acrosterigma dampierense* Wilson & Stevenson, 1977**

See Vidal (1999: 305–308) for arguments considering *A. damperiense*, *A. vlamingi* and *A. rosemariensis* synonymous with *A. impolitum*. Pending additional research, his views are followed here.

***Nemocardium* (*Nemocardium*) *bechei* (Reeve, 1840)**

Ter Poorten (2013) has argued that shape, ribbing and colour of Australian samples differ considerably from that of other provenances, that it is in agreement with *Pratulum probatum* Iredale, 1927, and that it is to be separated at species level. Ter Poorten (2013) also indicated that among WA and QLD populations differences in morphology and size are present and that distributions are discrete. This study reinforces these findings, as no material is present from NT (except for one WAM record just within the NT boundary) and the Gulf of Carpentaria. Moreover, the QLD population is strongly restricted to the southern part. The shallow and narrow Torres Strait may act as a dispersal barrier, preventing gene flow, hence the presence of sister species pairs seems likely. Given the very limited availability of adult WA samples and lacking the opportunity of molecular testing, we refrain from taxonomic separation.

***Nemocardium* (*Microcardium*) *torresi* (Smith, 1885)**

Although *Frigidocardium torresi* does occur in WA, all Wilson and Stevenson (1977) records either refer to *Frigidocardium eos* (Kuroda, 1929) or to *F. helios* ter Poorten & Poutiers, 2009. All three taxa are treated in the systematic section.

***Nemocardium* (*Microcardium*) *exasperatum* (Sowerby, 1838)**

Huber and ter Poorten (2007) demonstrated that *F. exasperatum* is restricted from S. Japan to Vietnam. Australian material attributed to this species either involves *F. eos* (Kuroda, 1929) or *F. iris* Huber & ter Poorten, 2007.

***Nemocardium* (*Pratulum*) *thetidis* (Hedley, 1902)**

Ter Poorten (2013) raised *Pratulum* to generic level. *Pratulum thetidis* as recognised by Wilson and Stevenson (1977) is a composite of two species, one of these is new to science (*P. occidentale* sp. nov.) and is treated in the systematic section (see ter Poorten 2013 for further generic explanation).

***'Cardium' victor* Angas, 1872**

The generic attribution has long been the subject of discussion. Recent phylogenetic research (Kirkendale 2009; Herrera et al. 2015) confirmed that this species is only distantly related to *Ctenocardia* and the subfamily Fraginae. Ter Poorten (2009) demonstrated that inclusion in *Freneixicardia* is appropriate.

Taxa not treated by Wilson and Stevenson (1977)

Recent morphological and molecular phylogenetic research (Schneider 1998; Keys and Healy 1999, Schneider and Ó Foighil 1999 and Herrera et al. 2015) has shown that the tridacnines are a distinct and highly specialised subfamily of the Cardiidae. Giant clams were not treated by Wilson and Stevenson (1977), because they were placed in a separate family, the Tridacnidae at that time. For the purposes of this paper, giant clams are not further treated in the systematic section but enumerated below, with references to their occurrence in WA. Additionally, these seven species are listed in the Results section, including their distributional data (North/East and South/East range endpoints in WA). References to the giant clam species *Tridacna noae* (Röding, 1798), recently ressurrected from synonymy (Borsa et al. 2015), all relate to dry, non-genotyped material: in some cases tentatively assigned to this species given the limited utility of currently available morphological character data in resolving species boundaries (Borsa et al. 2015, Johnson et al. 2016). *Tridacna ningaloo* Penny & Willan, 2014 is considered a junior synonym of *T. noae*. This group is the subject of ongoing research in the region by the second author.

1. *Hippopus hippopus* (Linnaeus, 1758) — Rosewater (1965); Wells and Slack-Smith (1986); Lamprell and Whitehead (1992); Wells (1993); Willan (2005); Bryce and Whisson (2009).
2. *Tridacna* (*Chametrachea*) *crocea* Lamarck, 1819 — Wells Slack-Smith (1986); Lamprell and Whitehead (1992); Wells (1993); Willan (2005); Bryce and Whisson (2009).
3. *Tridacna* (*Chametrachea*) *maxima* (Röding, 1798) — Rosewater (1965); Wells and Slack-Smith (1986); Lamprell and Whitehead (1992); Willan (2005); Bryce and Whisson (2009).
4. *Tridacna* (*Chametrachea*) *noae* (Röding, 1798) — Borsa et al. (2014); Penny and Willan (2014, as *T. ningaloo*).
5. *Tridacna* (*Chametrachea*) *squamosa* Lamarck, 1819 — Hedley (1921); Wells and Slack-Smith (1986); Lamprell and Whitehead (1992); Wells (1993); Willan (2005); Bryce and Whisson (2009).
6. *Tridacna* (*Tridacna*) *derasa* (Röding, 1798) — Bryce and Whisson (2009).
7. *Tridacna* (*Tridacna*) *gigas* (Linnaeus, 1758) — Wells and Bryce (1985); Wells and Slack-Smith (1986); Lamprell and Whitehead (1992); Wells (1993); Willan (2005); Bryce and Whisson (2009).

Family Cardiidae Lamarck, 1819

incertae sedis

REMARKS

The genera *Frigidocardium*, *Microcardium*, *Nemocardium, Trifaricardium* and *Pratulum* treated in the present work were traditionally assigned to Protocardiinae. However, in his cladistic analysis of Cardiidae, Schneider (1995) restricted this subfamily to a group of extinct Mesozoic taxa and classified *Nemocardium* in Laevicardiinae, together with the subgenera *Frigidocardium*, *Microcardium, Trifaricardium* and *Pratulum*. These taxa were raised to genus by ter Poorten (2013). In their molecular phylogenetic study, Herrera et al. (2015) demonstrated that Laevicardiinae is polyphyletic, with *Frigidocardium*, *Microcardium* and *Trifaricardium* distributed in a clade basal to all other living cardiids; and that Laevicardiinae is sister to Trachycardiinae, both forming the youngest lineages of the family. Unfortunately, the study of Herrera et al. (2015) did not include members of the oldest extant cardiid genera: *Nemocardium* and *Pratulum*. Hence, subfamily assignment of these and related genera must await further research.

Genus *Frigidocardium* Habe, 1951

Erigidocardium [sic! = *Frigidocardium*] Habe, 1951: 152 (as a subgenus of *Nemocardium*). Type species by original designation: *Cardium* (*Fragum*?) *eos* Kuroda, 1929; Recent, Kii Peninsula, Honshū, Japan.

Frigidocardium eos (Kuroda, 1929)

Figures 2A–F, 17A

Cardium (*Fragum?*) *eos* Kuroda, 1929: 93, pl. 3 fig. 5.

Nemocardium (*Microcardium*) *torresi* (Smith, 1885) — Wilson and Stevenson (1977) 1977: 65–66, pl. 4 figs 20–22, text fig. 8 [*pars*].

Frigidocardium torresi (Smith, 1885) — Lamprell and Whitehead 1992: pl. 33 fig. 219 (Philippine specimen figured).

Frigidocardium eos (Kuroda, 1929) — ter Poorten 2009: pl. 17 figs 1–4, pl. 20 fig. 3; Huber 2010: 307, fig.; ter Poorten 2011: pl. 1105 figs 5–7.

MATERIAL EXAMINED

Australia, *Western Australia*: Oceanic Shoals, Kulumburu L293.4607°S, 124.0199°E to 13.4726°S, 124.024°E, 101–104 m, 06.07.2007. Leg. M.P. Salotti, CSIRO RV 'Southern Surveyor' Cruise, Stn SS0507/171 (WAM S32879, 1 s.v.); **North West Shelf**, 50 miles N.N.E. of Adele Island, 15°30'S, 123°09'E, 50 fms (91 m), 20.10.1962. Leg. R.W. George, 'Dorothea' (WAM S78147, ex 228–67, 1 s.v.); 25 miles N.N.E. of Adele Island, 15°30'S, 123°09'E, 42 fms (77 m), 20.10.1962. Leg. R.W. George, 'Dorothea' (WAM S78146, ex 326–67, 1 s.v.); Adele Island L28, 14.5622°S, 122.9182°E to 14.5614°S, 122.9151°E, 95–105 m, 05.07.2007. Leg. M.P. Salotti, CSIRO RV 'Southern Surveyor' Cruise, Stn SS0507/161 (WAM S34671, 1 s.v.); Adele Island L28, 14.5615°S, 122.9062°E to 14.5502°S, 122.911°E, 135–165 m, 05.07.2007. Leg. M.P. Salotti, CSIRO RV 'Southern Surveyor' Cruise, Stn SS0507/162 (WAM S78304, 1 s.v.); Leveque L27, 15.0945°S, 121.7864°E to 15.0916°S, 121.7904°E, 78–79 m, 02.07.2007. Leg. M.P. Salotti, CSIRO RV 'Southern Surveyor' Cruise, Stn SS0507/140 (WAM S32788, 1 p.v., A); Rowley Shoals, S.E. of Imperieuse Reef L23, 18.4602°S, 120.1447°E to 18.462°S, 120.1447°E, 80–81 m, 19.06.2007. Leg. C. Whisson & O. Gomez, CSIRO RV 'Southern Surveyor' Cruise, Stn SS0507/082 (WAM S32786, 1 p.v., A; WAM S32865, 25 s.v.); Rowley Shoals, S.E. of Imperieuse Reef L23, 18.4293°S, 120.0981°E, 104 m, 19.06.2007. Leg. C. Whisson & O. Gomez, CSIRO RV 'Southern Surveyor' Cruise, Stn SS0507/083 (WAM S32887, 2 s.v.); S.E. of Mermaid Reef, 17°46'6.23"S, 120°43'9.12"E to 17°45'56.87"S, 120°42'56.51"E, 97–109 m, 20.06.2007. Leg. C. Whisson & O. Gomez, CSIRO RV 'Southern Surveyor' Cruise, Stn SS0507/097 (WAM S32857, 1 s.v.); 17.7605°S, 120.7111°E, 110 m, 19.06.2007. Leg. C. Whisson & O. Gomez, CSIRO RV 'Southern Surveyor' Cruise, Stn SS0507/089 (WAM S32868, 1 s.v.); 84 nautical miles N. of Port Hedland, 18°53'12"S, 118°34'12"E to 18°53'06"S, 118°32'18"E, 89–92 m, 20.08.1982, leg. J. Marshall, CSIRO FRV 'Soela' Cruise IV, Stn SO4B/82/77 (WAM S15909, 1 s.v.); 67 nautical miles N.N.E. of Cape Lambert, 19°31.4'S, 117°26.0'E to 19°29.9'S, 117°26.4'E, on sand, 78 m, 17.08.1995, leg. L.M. Marsh, AIMS Survey RV 'Lady Basten', Stn AIMS/95/LB3 (WAM S15924, 1 s.v.); **Pilbara Offshore**, 10–20 miles N.N.W. of Anchor Island, Onslow, 21°38'S, 115°07'E, mud & gravel, 119 m, 17.06.1960. Leg. B.R. Wilson, R. George & L. Joll, Mariel King Hawaiian Exped. MV 'Davena' (WAM S35204, ex 248–67, 1 s.v.); Off Barrow Island, 20.9847°S, 114.9070°E to 20.9945°S, 114.9090°E, 100–101 m, 13.12.2005. Leg. S.M. Slack-Smith, & M.P. Salotti, CSIRO RV 'Southern Surveyor' Cruise SS1005 Nov/Dec 2005, Stn SS1005/170 (WAM S29449, 1 s.v.); Off Barrow Island, 21.0316°S, 114.8920°E to 21.0344°S, 114.8880°E, 93 m, 13.12.2005. Leg. S.M. Slack-Smith, & M.P. Salotti, CSIRO RV 'Southern Surveyor' Cruise SS1005 Nov/Dec 2005, Stn SS1005/169 (WAM S29391, 1 p.v., A); Off Barrow Island, 21.0358°S, 114.888°E to 21.0332°S, 114.8857°E, 90–100 m, 10.06.2007. Leg. C. Whisson, CSIRO RV 'Southern Surveyor' Cruise, Stn SS0507/008 (WAM S32784, 1 p.v., A; S32863, 1 s.v.); **Ningaloo**, W. of North West Cape, 21°50'S, 113°46'E, 75 fms (137 m), 06.10.1963. CSIRO HMAS 'Diamantina' Cruise II, Stn DM6/173/63 (WAM S78144, ex 327–67, 1 s.v.); Off Ningaloo (South), 22.0795°S, 113.7960°E to 22.0873°S, 113.7940°E, 201–206 m, 10.12.2005. Leg. S.M. Slack-Smith, & M.P. Salotti, CSIRO RV 'Southern Surveyor' Cruise SS1005 Nov/Dec

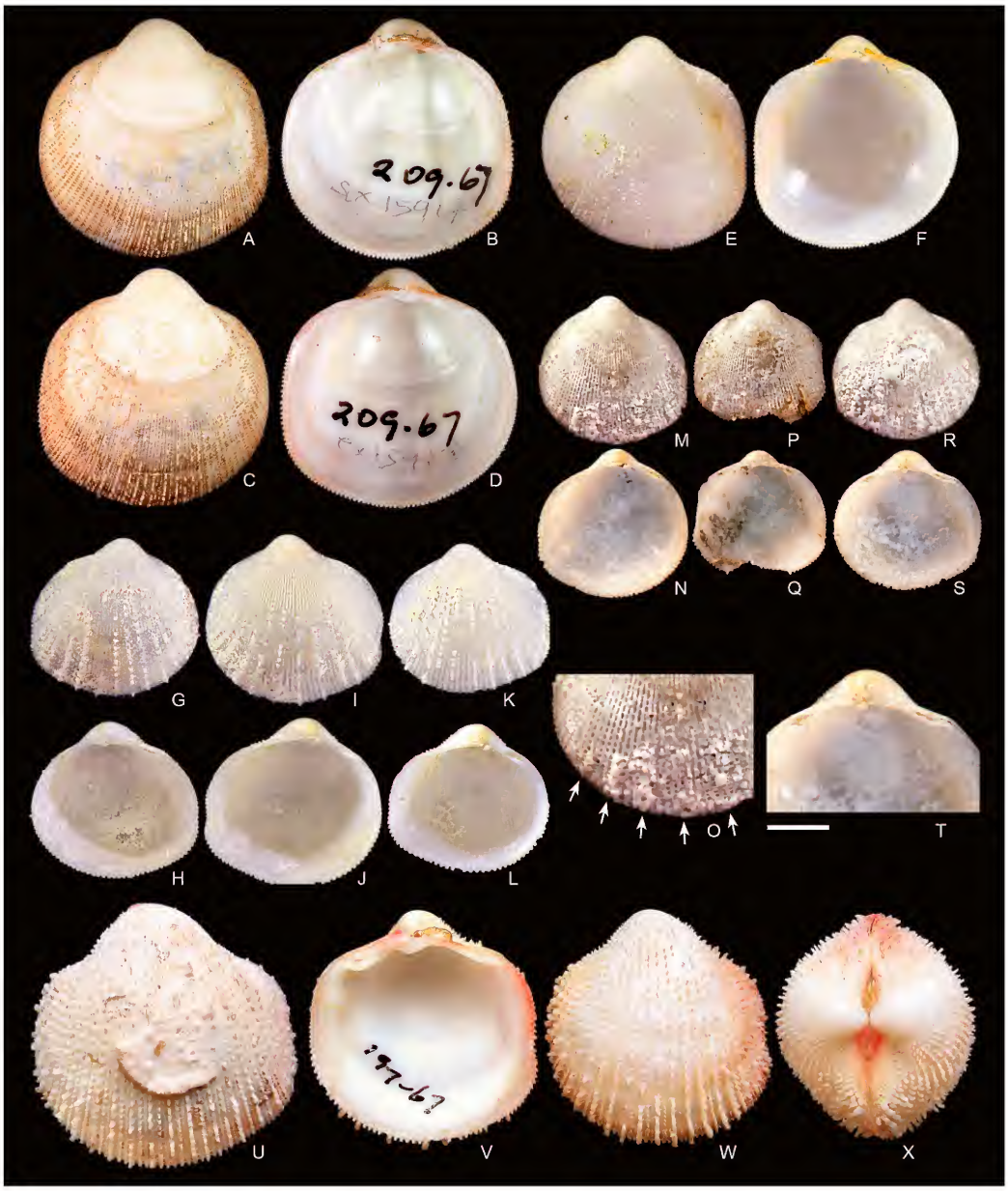

FIGURE 2 A, B, C, D, E, F, *Frigidocardium eos* (Kuroda, 1929). A–D, W. of Point Cloates, WA: WAM S15917, height 13.5 mm; A, exterior of l.v., B, interior of r.v., C, exterior of r.v., D, interior of l.v.; E–F, N.W. of Bunbury, WA: WAM S84345, height 10.3 mm. E exterior of l.v., F interior of l.v.

G, H, I, J, K, L, M, N, O, P, Q, R, S, T, *Frigidocardium torresi* (E.A. Smith, 1885). G–L, N.W. of Port Hedland, WA: WAM S15902. G–H, length 5.0 mm, G, exterior of r.v., H, interior of r.v.; I–J, length 5.3 mm, I, exterior of l.v., J, interior of l.v.; K–L, length 4.8 mm, K, exterior of l.v., L, interior of l.v.; M–T, S. of Papua, Indonesia: NHMUK 1887.2.9.2736, three syntypes. M–O, length 4.2 mm, M, exterior of l.v., N, interior of l.v., O, ventral slope of l.v., P–Q, length 3.7 mm (defect), P, exterior of r.v., Q, interior of r.v., R–T, length 4.1 mm, R, exterior of r.v., S, interior of r.v., T, hinge of r.v.

U, V, W, X, *Frigidocardium iris* Huber & ter Poorten, 2007. U, N.N.W. of Anchor Island, WA: WAM S15896, length 24.6 mm, exterior of l.v.; V–X, Cabulan Island, Philippines: WAM S15898, paratype, height 21.0 mm. V, interior of r.v., W, exterior of l.v., X, dorsal. Scale bar: 1 mm.

2005, Stn SS1005/146 (WAM S29309, 2 s.v.); Ningaloo Marine Park, 22°5'24"S, 113°49'37"E to 22°5'25"S, 113°49'32"E, 83–85 m, 10.02.2008. Leg. S.M. Slack-Smith & M.P. Salotti, AIMS RV 'Solander' Cruise, Stn RVS4545-D130 (WAM S43512, 1 s.v.); Ningaloo Marine Park, off Osprey Sanctuary Zone, 22°17.455'S, 113°45.237'E to 22°17.139'S, 113°45.361'E, 88–91 m, 27.04.2006. Leg. M.P. Salotti, AIMS-WAM RV 'Cape Ferguson' Ningaloo Survey I, Stn CF4010&11/2006/D008 (WAM S78253, 1 s.v.); Ningaloo Marine Park, 22°27'60"S, 113°29'12"E to 22°27'1"S, 113°38'11"E, 102–110 m, 09.02.2008. Leg. S.M. Slack-Smith, AIMS RV 'Solander' Cruise, Stn RVS4545-D129 (WAM S43496, 1 s.v.); Off Point Cloates, 22.8487°S, 113.5110°E to 22.8583°S, 113.5140°E, 100 m, 09.12.2005. Leg. S.M. Slack-Smith, & M.P. Salotti, CSIRO RV 'Southern Surveyor' Cruise SS1005 Nov/Dec 2005, Stn SS1005/135 (WAM S29390, 2 p.v., A); Off Point Cloates, 22.8504°S, 113.5110°E to 22.8554°S, 113.5130°E, 100 m, 09.12.2005. Leg. S.M. Slack-Smith, & M.P. Salotti, CSIRO RV 'Southern Surveyor' Cruise SS1005 Nov/Dec 2005, Stn SS1005/139 (WAM S29392, 1 s.v.); W. of Point Cloates, 22°52'S, 113°29'E, 73 fms (133 m), 06.10.1963. CSIRO HMAS 'Diamantina' Cruise II 1963, Stn DM6/128/63 (WAM S15917, ex 209–67, 2 p.v.); **Leeuwin-Naturaliste**, N.W. of Bunbury, 33°00'S, 114°52'E, 115–122 m, 17.02.1964. Leg. CSIRO Staff (WAM S84345, 1 s.v.).

DESCRIPTION

Shell relatively large (H 25–30 mm), rather fragile, inflated, ovate-quadrangular and slightly inequilateral. Length and height about equal. Ribbing structure homogeneous, with between 130–145 radial ribs covering the whole surface, all sculptured on anterior side with a row of erect but delicate spines of distinctly alternating strength, becoming slightly spatulate anteriorly and coarser posteriorly; commarginal sculpture of rib interstices usually inconspicuous. Lunular heart well defined, elevated, orange coloured and rather broad, variably rounded to flattened on top. Lunular area finely sculptured but with no clear border; lunular margin straight. Shell exterior white and often radially and commarginally streaked orange, lunule orange, umbo mostly yellowish. Entire shell occasionally pure lemon yellow, interior white with pinkish posterior zone and yellowish umbonal cavity.

DISTRIBUTION AND ECOLOGY

Mainly found in northern WA near the edge of the continental shelf (Figure 17A). Depth range of live taken samples 78–100 metres. Widely distributed in the Central IWP.

REMARKS

It has become evident that Wilson and Stevenson (1977) based their opinion of *F. torresi* on the incorrect assumption that the type material would be juvenile (Huber and ter Poorten 2007). This possibility was already taken into account by Smith (1885). As a consequence, Lamprell and Whitehead (1992: sp. 219) figured *F. eos* (a specimen from Philippines, Sulu Archipelago, WAM S78153, ex 99-67) under the same name. However, *F. torresi* is clearly differentiated by its lower rib number (75–90) versus 130–145 for *eos* (see ter Poorten 2009: table 7 for other differentiating characters). *Frigidocardium* is a tropical genus occurring in deep water, hence it is limited to the offshore waters of WA. *Frigiocardium iris* shows an almost identical WA distribution pattern, except for sample WAM S84345 (Figures 2E–F), which is by far the southernmost record of *F. eos* and also of the genus. As it is a CSIRO expedition sample, the locality is considered trustworthy. This record is consistent with other records from a range of taxa along this coastline highlighting the incidence of tropical vagrants pushing southward.

Frigidocardium helios ter Poorten & Poutiers, 2009

Figures 3A–H

Nemocardium (*Microcardium*) *torresi* (Smith, 1885) — Wilson and Stevenson 1977: 65–66 [*pars*].

Frigidocardium helios ter Poorten & Poutiers in ter Poorten, 2009: 64–65, pl. 18 figs 1–6, pl. 19 fig. 2, pl. 20 fig. 1.

Frigidocardium helios ter Poorten & Poutiers in ter Poorten, 2009 — ter Poorten 2011: pl. 1105 fig. 1.

MATERIAL EXAMINED

Australia: ***Western Australia:*** **Pilbara Offshore**, Onslow, 7 mls (11 km) N. of Long Island, off Onslow, 21°31'S, 114°40'E, 28 fms (51 m), fine sand and rubble, 17.06.1960. Western Australian Hawaiian Exped., hauls 9–11 (WAM S78145, ex 189-67, 1 s.v.); **Ningaloo**, Off Point Cloates, 22.8487°S, 113.5110°E, 100 m, 09.12.2005. Leg. S.M. Slack-Smith & M.P. Salotti, CSIRO RV 'Southern Surveyor' Cruise SS1005 Nov/Dec 2005, Stn SS1005/135 (WAM S29441, 2 p.v., A).

DESCRIPTION

Shell relatively small (L 7–9.5 mm), thin, moderately inflated, ovate-quadrangular and slightly inequilateral. Length slightly exceeds height. Anterior and ventral margins rounded, posterior margin truncate, nearly straight. Ribbing structure homogeneous, with between 130–175 low radial riblets covering the whole surface and about 44–66 primary radial rows of tiny spines originating from the interstices. Spiny rows alternating with the remaining interstices that carry thin crossbars. Secondary sculptured rows restricted to antero-dorsal part, limited to 1–3 rows, if present at all. Lunular area finely sculptured, not sharply delimited, margin a little sinuous. Lunular heart small, broad and elevated. Shell exterior white, often vaguely radially and commarginally streaked orange with a reddish-orange stain near postero-

dorsal margin; umbonal tip reddish, lunular area with a distinct yellow-orange hue; interior same colouration because of the translucency of the shell.

DISTRIBUTION AND ECOLOGY

WA records are from the north, with a single live taken sample from 100 meters depth and this species has a wide IWP distribution. Supplementary to the distribution given by ter Poorten (2009), additional material has become available from the Red Sea (ter Poorten and van Gemert 2016), N. Madagascar and Fiji (both MNHN, det. TP).

REMARKS

These represent the first Australian records of this recently described species. The MNHN holotype is figured herein for comparison (Figures 3C–D). Its former identification as *F. torresi* is indicative of the challenging taxonomy within the genus *Frigidocardium* (see also remarks under *F. eos*).

Frigidocardium iris
Huber & ter Poorten, 2007

Figures 2U–X, 17B

Nemocardium (*Microcardium*) *exasperatum* (Sowerby, 1838) — Wilson and Stevenson 1977: 67–68, pl. 4 figs 18 (= WAM S15889, paratype) 19 (= WAM S15898, paratype), text fig. 9 (not figs 14–17).

Frigidocardium exasperatum (Sowerby, 1838) — Lamprell and Whitehead 1992: pl. 33 fig. 220 [Philippine specimen figured].

Frigidocardium iris Huber & ter Poorten, 2007: 105–107, pl. 1 figs 1–10, pl. 2 figs 7–10.

Frigidocardium iris Huber & ter Poorten, 2007 — ter Poorten 2009: pl. 17 figs 5–7, pl. 20 fig. 5; Huber 2010: 307, fig.; ter Poorten 2011: pl. 1106 figs 4–7.

MATERIAL EXAMINED

Australia: ***Western Australia:*** **Oceanic Shoals**, E. of Cartier Reef, 11 nautical miles S. of Barracouta Shoal, Osborn Passage, 12°42.86'S, 123°57.98'E, 180 m. Leg. R.S. Williams (NTM P.8600, 6 s.v.); **North West Shelf**, N. of Adele Island L28, 14.5615°S, 122.9062°E to 14.5502°S, 122.911°E, 135–165 m, 05.07.2007. Leg. M.P. Salotti, CSIRO RV 'Southern Surveyor' Cruise, Stn SS0507/162 (WAM S32878, 1 s.v.); S.E. of Mermaid Reef, 17.4872°S, 120.4606°E to 17.4954°S, 120.4679°E, 184–187 m, 20.06.2007. Leg. C. Whisson & O. Gomez, CSIRO RV 'Southern Surveyor' Cruise, Stn SS0507/091 (WAM S32889, 2 s.v.); S.E. of Imperieuse Reef L23, 18.4253°S, 120.0987°E to 18.4368°S, 120.1082°E, 103–105 m, 19.06.2007. Leg. C. Whisson & O. Gomez, CSIRO RV 'Southern Surveyor' Cruise, Stn SS0507/085 (WAM S32888, 3 s.v.); 115 nautical miles N. of Port Hedland, 18°24'S, 118°31'E to 18°24'S, 118°29'E, sand or mud, 154–156 m, 28.03.1982. Leg. L.M. Marsh, CSIRO FRV 'Soela' Cruise II, Stn SO2/82/08 (WAM S15899, 2 s.v.); 129 nautical miles N.E. of Cape Lambert, 18°42.8'S, 118°03.2'E to 18°39.6'S, 118°06.3'E, limestone rubble and shells, 150–160 m, 18.08.1995. Leg. L.M. Marsh et al., AIMS Survey RV 'Lady Basten', Stn AIMS/95/LB5A (WAM S15925, 3 s.v.); 100 nautical miles N.W. of Port Hedland, 18°47'S, 117°58'E, grey mud & shell rubble, 154 m, 28.03.1982. Leg. L.M. Marsh, CSIRO FRV 'Soela' Cruise II, Stn SO2/82/10A (WAM S15905, 1 s.v.); 37 miles N.W. of Enderby Island, 20°07.1'S, 116°06.1'E to 20°06.0'S, 116°04.4'E, shelly sand, 56–58 m, 29.09.1982. Leg. L.M. Marsh, & M. Bezant, CSIRO FRV 'Soela' Cruise V, Stn SO5/82/24 (WAM S15910, 1 s.v.); **Pilbara Offshore**, 10–20 miles (32 km) N.N.W. of Anchor Island, Onslow, 21°38'S, 115°07'E, mud & gravel, 65 fms (119 m), 17.06.1960. Leg. B.R. Wilson, R. George & L. Joll, Mariel King Hawaiian Exped. MV 'Davena' (WAM S15895, ex 248-67, 1 s.v.; WAM S15896, ex 292-67, 1 s.v.); Off Barrow Island, 21.0358°S, 114.888°E to 21.0332°S, 114.8857°E, 90–100 m, 10.06.2007. Leg. C. Whisson, CSIRO RV 'Southern Surveyor' Cruise, Stn SS0507/008 (WAM S32862, 1 s.v.); **Ningaloo**, W. of North West Cape, 21°48'S, 113°56'E, 60–70 fms (110–128 m), 01.02.1964. CSIRO HMAS 'Diamatina' Cruise III, Stn DM1/124/64 (WAM S15894, ex 210-67, 1 s.v.); Ningaloo Marine Park, Mandu Creek, 22°8'33"S, 113°47'37"E to 22°8'35"S, 113°47'36"E, 109–110 m, 18.08.2008. Leg. O.A. Gomez & J. Colquhoun, AIMS-WAM RV 'Cape Ferguson' Ningaloo Survey IV, Stn SOL4769/2008/1-017SL01 (WAM S43899, 1 s.v.); Ningaloo Marine Park, 22°14'55"S, 113°45'26"E to 22°16'20"S, 113°45'11"E, 100–104 m, 26.04.2006. Leg. M.P. Salotti, AIMS-WAM RV 'Cape Ferguson' Ningaloo Survey I, Stn CF4010&11/2006/D007 (WAM S78136, 1 s.v.); Ningaloo Marine Park, 22°15'46"S, 113°44'58"E to 22°15'37"S, 113°45'1"E, 115 m, 27.04.2006. Leg. M.P. Salotti, AIMS-WAM RV 'Cape Ferguson' Ningaloo Survey I, Stn CF4010&11-D009 (WAM S78135, 1 s.v.); **Undefined bioregion**, 'Between Shark Bay and Onslow', 1966. Leg. W. & W. Poole Bros (WAM S78143, 1 s.v.).

DESCRIPTION

Shell relatively large (H 25–28 mm), rather thin, inflated, ovate-quadrangular and subequilateral. Length approximately equal to height. Ribbing structure homogeneous, with over 100 radial ribs covering the whole surface, of which between 30–40 bear finely upright spines, positioned on the sides and becoming slightly larger and more crowded posteriorly and spatulate to almost knobby anteriorly. Primary rib sculpture regularly alternating with row of tiny secondary spines, also positioned on the rib sides. Interstices with poorly developed cross-striae, sometimes

lacking. Lunule well delimited and weakly sculptured, lunular heart well defined, forming a rounded ovate bulge of the dorsal margin. Exterior white, usually with red collars, commarginally arranged and more prominent towards the margins; sometimes almost all pinkish-red or white Interior white, umbonal cavity usually deep yellow. Lunular area generally deep orange-red.

DISTRIBUTION AND ECOLOGY

Presence in northern WA and Ningaloo well established and based on numerous records, often found near the edge of the continental shelf (Figure 17B) but exclusively consisting of loose valves (depth range 56–187 metres), mostly rather worn. Widely distributed in the Central IWP.

REMARKS

Huber and ter Poorten (2007) demonstrated that the supposed type locality of *F. exasperatum* (G.B. Sowerby II, 1839), 'Swan River' (Western Australia, Perth, Swan River), was erroneous and emended it to Taiwan. While *F. exasperatum* is restricted to southern Japan-China-Vietnam, *F. iris* ranges from Philippines through to Indonesia and along to the northern coast of WA, thus the two sister species exhibit a classic parapatric distribution.

Frigidocardium torresi (E.A. Smith, 1885)

Figures 2G–T, 17C

Cardium (*Fragum*) *torresi* E.A. Smith, 1885: 164–165, pl. 8 figs 4, 4a–b.

Frigidocardium torresi (E.A. Smith, 1885) — ter Poorten 2009: pl. 17 figs 11–15, pl. 19 fig. 3, pl. 20 fig. 6; Huber 2010: 307, fig.; ter Poorten 2011: pl. 1106 figs 1–3.

Not: *Nemocardium* (*Microcardium*) *torresi* (Smith, 1885) — Wilson and Stevenson 1977: 65–66, pl. 4 figs 20–22, text fig. 8 (= *F. eos*).

Not: *Frigidocardium torresi* (Smith, 1885) — Lamprell and Whitehead 1992: pl. 33 fig. 219 (= *F. eos*).

MATERIAL EXAMINED

Indonesia: S. of Papua, N. of Gulf of Carpentaria, 09°59'S, 139°42'E, 28 fms. [51 m], 10.09.1874. Challenger Exp. stn. 188 (NHMUK 1887.2.9.2736, three syntypes, all s.v.).

Australia: ***Northern Territory:*** **Oceanic Shoals**, southern Timor Sea, NW. corner of Melville Island, approx. 50 km due W. of Cape Van Diemen, southern Van Diemen Rise, 11°3.262'S, 129°52.344'E, 76.2 m, 24.08.2010. Leg. B. Alvarez (NTM P.52732, 1 p.v., A); N. of eastern section of Jospeh Bonaparte Gulf, Melville Island, approx. 125 km N.W. of Cape Van Diemen, northern Van Diemen Rise, 10°26.956'S, 129°28.966'E, 134.9 m, 18.08.2010. Leg. B. Alvarez (NTM P.52468, 1 p.v.); northern Van Diemen Rise, 10°33.086'S, 129°28.700'E, 67.7 m, 20.08.2010. Leg. B. Alvarez (NTM P.49938, 1 p.v.).

Australia: ***Western Australia:*** **Canning**, W. of Broome, 17°58'S, 122°14'E, 90 m, 21.12.1969. Leg. K. Ozawa, Tokyo Uni of Fisheries Exped. FV 'Umataka Maru', Stn UMD6927 (WAM S57167, 3 s.v.); **Oceanic Shoals**, Rowley Shoals, Clerke Reef, 17°20'S, 119°10'E, 266 m, 20.12.1969. Leg. K. Ozawa, Tokyo Uni of Fisheries Exped. FV 'Umitaka Maru', Stn UMD/69/26 (WAM S15913, 1 s.v. WAM S15915, 2 s.v.); **North West Shelf**, 86 nautical miles N.N.W. of Port Hedland, 18°54'S, 118°22'E to 18°52'S, 118°21'E, from white gorgonians, 102 m, 27.03.1982. Leg. L.M. Marsh, CSIRO FRV 'Soela' Cruise II, Stn SO2/82/05 (WAM S15907, 1 s.v.); 100 nautical miles N.W. of Port Hedland, 18°47'S, 117°58'E, grey mud and shell rubble, 154 m, 28.03.1982. Leg. L.M. Marsh, CSIRO FRV 'Soela' Cruise II, Stn SO2/82/10A (WAM S15900, 1 s.v.; WAM S15902, 6 s.v.); 109 nautical miles N.W. of Port Hedland, 18°56'S, 117°21'E to 18°57'S, 117°19'E, limestone rocks and mud, 201–202 m, 14.04.1982, Leg. L.M. Marsh, CSIRO FRV 'Soela' Cruise II, Stn SO2/82/048 (WAM S15901, 3 s.v.); N.N.E. of Dampier Archipelago, 19°23'S, 117°21'E to 19°23'S, 117°23'E, 101–102 m, 11.03.1981. Leg. N. Sinclair, 'Hai Kung' Survey (WAM S78287, 1 s.v.).

DESCRIPTION

Shell relatively small (L 5–9 mm), thickness rather variable, well inflated, quadrangular, with truncated posterior margin, sometimes slightly concave. Length usually slightly exceeds height. Sculpture homogeneous, with between 75–90 radial ribs covering the whole surface; ribs rather square-shaped and as wide as the interstices in median area, becoming lower and rounder towards dorsal margin. Between 22–32 radial rows of blunt spines or spoon-shaped projections, arising from the interstices. Secondary radial sculpture absent or confined to very few interstices. Radial spiny sculpture regularly alternating with interstices that carry well developed crossbars, somewhat differing in strength among specimens. Lunular heart smooth, rather long and narrow; lunular area unsculptured, not sharply bordered. Exterior colour white with reddish-orange umbonal tip, interior occasionally with similarly coloured umbonal cavity.

DISTRIBUTION AND ECOLOGY

The presence of *F. torresi* in WA is confirmed by several records, mainly off the northern coast at the edge of the continental shelf, between Dampier and Broome (Figure 17C). In WA it has been found in a depth range of 90–266 metres, based on single valves. The only live taken specimen is from NT, depth 76 metres. Not reported from QLD, but given the type locality (South of Papua) records are to be expected from northern QLD.

FIGURE 3 A, B, C, D, E, F, G, H, *Frigidocardium helios* ter Poorten & Poutiers, 2009. A–B, off Onslow, WA: WAM S78145, length 6.8 mm (defect). A, exterior of l.v., B, interior of l.v.; C–D, S.E. corner of Santo, Vanuatu: MNHN IM-2007-30161, holotype, length 7.3 mm. C, exterior of l.v., D exterior of r.v.; E–H, Aru, Indonesia: WAM S78140. E–F, length 5.1 mm, E, exterior of l.v., F, dorsal, G–H, length 6.6 mm, G, exterior of l.v., H, interior of l.v.

I, J, K, L M, *Microcardium scabrosum* sp. nov. I–J, N.W. of Port Hedland, WA: WAM S15906, holotype, height 11.3 mm; I exterior of l.v., J interior of l.v.; K–M, off North West Cape, WA: WAM S35202, length 9.8 mm. K–L, exterior of l.v. under different light conditions, M interior of l.v.

N, O, P, *Pratulum thetidis* (Hedley, 1902). Off Perth, WA: WAM S29300, length 8.5 mm. N, exterior of r.v., O, exterior of l.v., P, dorsal.

Q, R, S, T, *Microcardium sakuraii* (Habe, 1961). Q–R, W.N.W. of Lacepede Islands, WA: WAM S57161, height 10.8 mm, Q, exterior of l.v., R, interior of l.v.; S–T, off North West Cape, WA: TP 2044. S, height 16.5 mm, exterior of l.v., T, height 10.9 mm, exterior of l.v. 6 mm.

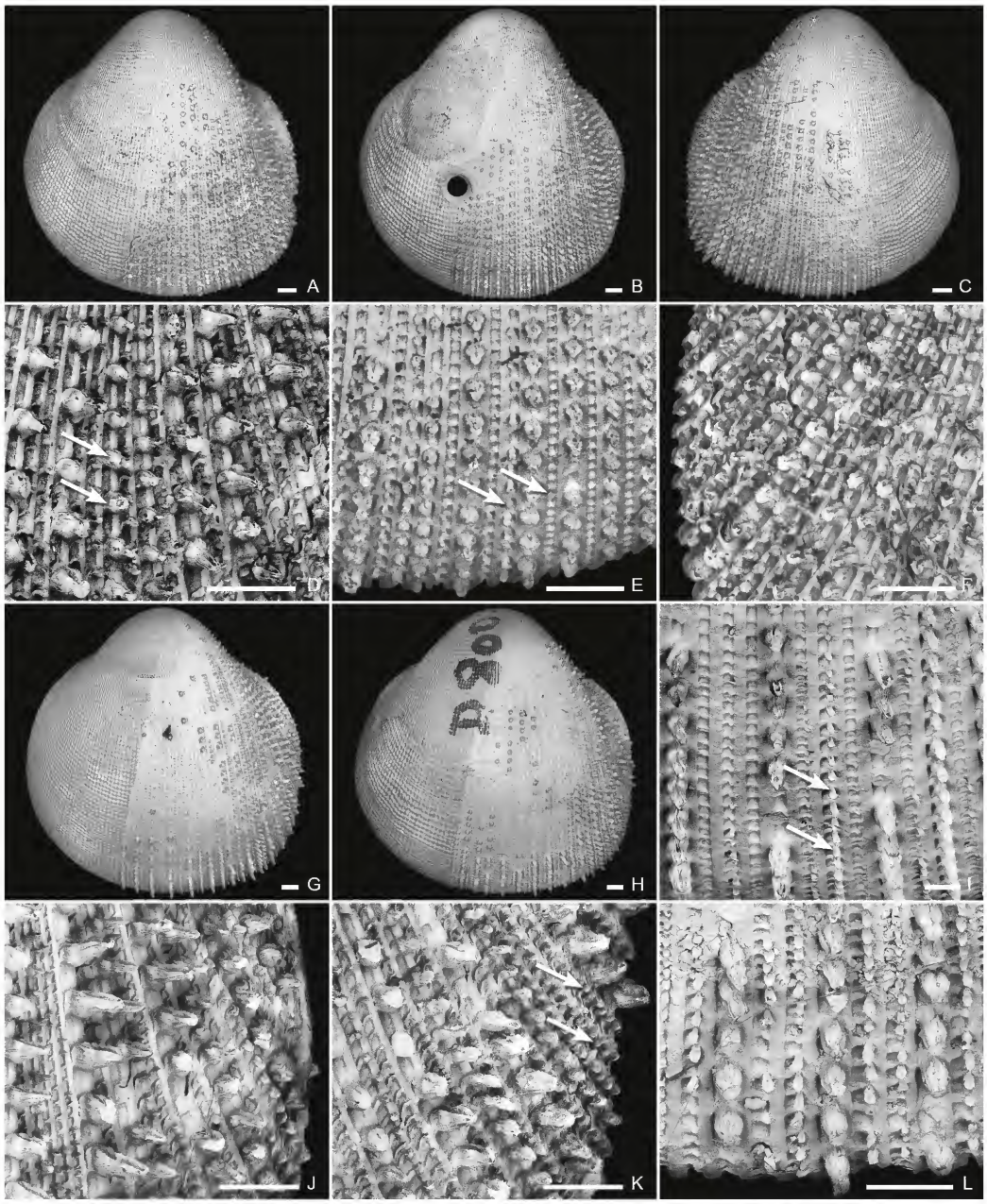

FIGURE 4 A, B, C, D, E, F, *Microcardium scabrosum* sp. nov. A,C,E–F, N. of Croker Island, NT: AMS C145.749, paratypes; A exterior of l.v., length 9.0 mm, C, exterior of r.v., length 9.1 mm, E, anterior part of posterior sculpture, F, posterior slope; B,D, N. of Goulburn Island, NT: AMS C145.746, paratype, length 11.2 mm. B, exterior of l.v., D, posterior slope.

G, H, I, J, K, L, *Microcardium gilchristi* (G.B. Sowerby III, 1904). G, I–K, SE of Port Durnford, Zululand: NM E4595, length 12.0 mm; G, exterior of r.v., I, anterior part of posterior sculpture, J–K, posterior slope; H,L, off Point Durnford, Zululand: NM D8005, length 11.4 mm. H, exterior of r.v., L, medial ventral margin. Scale bars: 0.5 mm.

REMARKS

All Wilson and Stevenson (1977) *F. torresi* records proved to represent *F. eos* (see also remarks under that species) or *F. helios* due to misinterpretation of the type material. The three poorly preserved NHMUK 1887.2.9.2736 syntypes (severely affected by Byne's disease) are figured herein for comparison (Figures 2M–T).

Genus *Microcardium* Keen, 1937

Microcardium Thiele, 1934: 878. (Not available, no type species designation — ICZN 1999: Art. 42.3.2).

Microcardium Keen, 1937: 14–15. Type species by original designation: *Cardium* (*Fulvia*) *peramabilis* Dall, 1881; Recent, 23°13'N, 89°16'W, off Yucatan, Mexico, 154 m.

Decussicardium Fischer-Piette, 1977: 94. Type species by monotypy: *Cardium gilchristi* G.B. Sowerby III, 1904; Recent, Algoa Bay, South Africa, 15 fms [27 m]. (Not available, no description and type species designation — ICZN 1999: Art. 13.1, 13.3).

Tobarum Noda, 1988: 74. Type species by original designation: *Frigidcardium* [sic! err. pro *Frigidocardium*] (*Tobarum*) *tobaruensis* Noda, 1988; Upper Pliocene, Shinzato Formation, Okinawa, Japan.

Microcardium sakuraii (Habe, 1961)

Figures 3Q–T, 17D

Nemocardium (*Microcardium*) *sakuraii* Habe, 1961: 152, 155–156, fig. 9.

Microcardium sakuraii (Habe, 1961) — ter Poorten 2009: pl. 20 fig. 7, pl. 21 figs 1–2; ter Poorten 2011: pl. 1113 figs 1–2.

Microcardium tenuilamellosum J.-M. Poutiers, 1981 — Huber 2010: 308, fig.

MATERIAL EXAMINED

Australia: ***Western Australia:*** **Oceanic Shoals**, N. of Browse Island, 14°06'S, 123°33'E (Egaz), 380 m, Stn UMD/69/30, leg. K. Ozawa, 23.12.1969 (WAM S57142, 1 s.v.); N.W. of Augustus Island, 13°33.3'S, 122°54.5'E to 13°34.3'S, 122°52.3'E, 390–394 m, 14.02.1984. Leg. S.M. Slack-Smith, CSIRO FRV 'Soela' Cruise VI, Stn SO1/84/073 (WAM S57163, 1 s.v.); N.W. of Collier Bay, 14°07.5'S, 122°29.4'E to 14°06.8'S, 122°31.7'E, 406–408 m, 13.02.1984. Leg. S.M. Slack-Smith, CSIRO FRV 'Soela' Cruise VI, Stn SO1/84/072 (WAM S57162, 1 s.v.); W.N.W. of Lacepede Islands, 15°51.2'S, 120°44.3'E to 15°49.3'S, 120°45.3'E, 348–350 m, 10.02.1984. Leg. S.M. Slack-Smith, CSIRO FRV 'Soela' Cruise VI, Stn SO1/84/054 (WAM S57161, 2 s.v.); Rowley Shoals, off Mermaid Reef L24 east, 17.0473°S, 119.6614°E to 17.0618°S, 119.6893°E, 424–456 m, 18.06.2007. Leg. C. Whisson & O. Gomez, CSIRO RV 'Southern Surveyor' Cruise, Stn SS0507/077 (WAM S32884, 1 s.v.); off Mermaid Reef L24 south, 17.1972°S, 119.5802°E to 17.2061°S, 119.5855°E, 435–438 m, 18.06.2007. Leg. C. Whisson & O. Gomez, CSIRO RV 'Southern Surveyor' Cruise, Stn SS0507/079 (WAM S32885, 9 s.v.); off Mermaid Reef L24 north, 17.0182°S, 119.591°E to 17.0302°S, 119.5833°E, 440–451 m, 18.06.2007. Leg. C. Whisson & O. Gomez, CSIRO RV 'Southern Surveyor' Cruise, Stn SS0507/080 (WAM S32886, 4 s.v.); Rowley Shoals, off Mermaid Reef, in sand and mud, by Scampi trawler, 400–450 m (TP 3567, 2 s.v.); Rowley Shoals, on sandy mud, 400–450 m (TP 3770, 3 s.v.); **Undefined bioregion**,'off Exmouth, North West Cape', trawled offshore on sand and mud, 400–500 m (TP 2044, 2 p.v.).

DESCRIPTION

Shell rather small (L up to 18 mm), rather thin, length approximately equal to height, rounded and inflated, nearly equilateral. Margins rounded, posterior margin straight or slightly concave. Inner margins finely crenulated. Between 125–145 radial riblets. Outer sculpture heterogeneous, divided into two markedly distinct sculptural zones. Anterior zone covering 60–65% of the shell, with tiny reticulate sculpture forming a pattern of undulating concentric ridges, stronger towards anterior margin. Posterior zone covering 35–40% of the shell, with barred sculpture, bearing well defined cross-bars in the interstices, each third to fifth interstice carrying small but erect, blunt spines; remainder unsculptured or occasionally carrying minute spinelets. Sculpture often becoming more laminate towards postero-dorsal margin. Demarcation line dividing the two zones directed obliquely in juveniles; and running parallel with the rib during subsequent ontogeny. Lunular heart mostly rather poorly developed and elevated, vaguely delimitated. Exterior and interior entirely white.

DISTRIBUTION AND ECOLOGY

Like its congeners, *M. sakuraii* is a deep water species found exclusively at the outer edge of the northern continental shelf down to a depth of at least 456 metres in WA (Figure 17D). Occurrence in WA was first reported by ter Poorten (2009). No records are known from NT or QLD. It is widely distributed in the Central IWP.

REMARKS

The deepest live-taken specimen was collected from 487–541 metres depth, Solomon Islands (MNHN-IM-2007-32245).

Microcardium scabrosum sp. nov. Poutiers

Figures 3I–M, 4A–F, 17E

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Microcardium sp. *A* Poutiers, 1992: 142, fig. 2k.

Microcardium gilchristi (Sowerby, 1904) — [*pars*] ter Poorten 2005: 9.

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia:*** **North West Shelf**, 100 nautical miles N.W. of Port Hedland, 18°47'S, 117°58'E, 154 m, 28.03.1982, Leg. L.M. Marsh, CSIRO FRV 'Soela' Cruise II 1982, Stn. SO2/82/10A (WAM S15906, 1 s.v.).

Paratypes

Indonesia: Arafura Sea, 320 km N. of Goulburn Island, 08°39'S, 133°34'E, sand, silt and clay, 192 m, 01.11.1969, Leg. P.H. Colman, MV 'San Pedro Sound' (BMR P69-1076 — AMS C145.746, 1 s.v., paratype).

Australia: ***Northern Territory:*** 100 miles N. of Croker Island, 09°30'S, 132°34'E, 124 m, 09.11.1969, Leg. P.H. Colman, MV 'San Pedro Sound' (AMS C145.749, 6 s.v., paratypes; MNHN-IM-2000-32636, 2 s.v., paratypes).

Australia: ***Western Australia:*** **North West Shelf**, 100 nautical miles N.W. of Port Hedland, 18°47'S, 117°58'E, 154 m, 28.03.1982, Leg. L.M. Marsh, CSIRO FRV 'Soela' Cruise II 1982, Stn. SO2/82/10A; WAM S99044, 1 s.v., paratype; WAM S99045, 5 s.v.); off North West Cape, on N.W. Shelf slope, 21°32.083'S, 114°07.53'E to 21°32.186'S, 114°08.115'E, 190 m, 25.03.2002. Stn 15, Leg. J. Fromont, L.M. Marsh & P. Alderslade (WAM S35202, 1 s.v., paratype).

Other material

Indonesia: Arafura Sea, Arnhem Land, 365 km N. of Milingimbi Island, 08°48'S, 134°58'E, clayey-sand, 100 m, 18.10.1969, Leg. P.H. Colman, MV 'San Pedro Sound' (BMR 985 — AMS C145.742, 1 s.v.); 420 km N. of Melville Island, 08°18'S, 134°11'E, sand, 141 m, 03.11.1969, Leg. P.H. Colman , MV 'San Pedro Sound' (BMR 1091 — AMS C145.743, 2 s.v.); 210 miles N. of Crocker Island, 08°18'S, 133°58'E, sand-silt-clay, 132 m, 03.11.1969, Leg. P.H. Colman, MV 'San Pedro Sound' (AMS C145.747, 38 s.v.).

Australia: ***Northern Territory:*** **Arafura Sea**, 230 km N. of Goulburn Island, 09°18'S, 133°38'E, clayey sand, 135 m, 01.11.1969, Leg. P.H. Colman, MV 'San Pedro Sound' (BMR P69-1073 — AMS C145.745, 3 s.v.); 320 km N. of Goulburn Island, 08°39'S, 133°34'E, sand, silt and clay, 192 m, 01.11.1969, Leg. P.H. Colman, MV 'San Pedro Sound' (BMR P69-1076 — AMS C145.746, 1 s.v.); 100 miles N. of Croker Island, 09°30'S, 132°34'E, 124 m, 09.11.1969, Leg. P.H. Colman, MV 'San Pedro Sound' (AMS C145.749, 30 s.v.); 205 km N. of Croker Island, 09°07'S, 132°33'E, clayey-sand, 218 m, 09.11.1969, Leg. P.H. Colman, MV 'San Pedro Sound' (BMR P69-1146 — AMS C145.741, 1 s.v.); **Oceanic Shoals**, 100 miles N. of Melville Island, 09°34'S, 131°22'E, 135 m, 15.11.1969, Leg. P.H. Colman, MV 'San Pedro Sound' (AMS C145.748, 7 s.v.); S. of Tanimbar Islands, 09°37'S, 131°02'E, 199–201 m, 04.11.1991, KARUBAR Exped. Stn DW80, NO 'Baruna Jaya 1' (MNHN-IM-2014-6066, 23 s.v.); 150 km N.W. of Melville Island, 09°53'S, 130°02'E, sand, 205 m, 05.12.1969, Leg. P.H. Colman, MV 'San Pedro Sound' (BMR 1220 — AMS C145.744, 1 s.v.).

Australia: ***Western Australia:*** **North West Shelf**, 100 nautical miles N.W. of Port Hedland, 18°47'S, 117°58'E, 154 m, 28.03.1982, Leg. L.M. Marsh, CSIRO FRV 'Soela' Cruise II 1982, Stn. SO2/82/10A (WAM S15906, 6 s.v.); **Ningaloo**, off North West Cape, on N.W. Shelf slope, 21°32.083'S, 114°07.53'E to 21°32.186'S, 114°08.115'E, 190 m, 25.03.2002. Stn 15, Leg. J. Fromont, L.M. Marsh & P. Alderslade (WAM S35202, 1 s.v.); off Ningaloo (South), 22.0795°S, 113.7960°E to 22.0873°S, 113.7940°E [22°04.77'S, 113°47.76'E to 22°05.24'S, 113°47.64'E], 201–206 m, 10.12.2005, Leg. S.M. Slack-Smith, & M.P. Salotti, CSIRO RV 'Southern Surveyor' Cruise SS1005 Nov/Dec 2005, Stn SS1005/146 (WAM S29448, 1 s.v.).

DESCRIPTION

Shell equivalve, inflated, moderately thin, subquadrate ovate in shape, usually nearly as high as long, rather small for the genus (up to about 11.9 mm long). Umbones moderately protruding, prosogyrate, usually positioned just anterior to mid-length of shell; in a few specimens, postumbonal side of valves sometimes tending to be a little drawn out posteriorly, giving the shell a slightly more inequilateral shape. Outline roughly rounded anteriorly and ventrally, somewhat truncate posteriorly.

Sculpture of the outer surface heterogeneous and divided into two markedly different sculptural zones. Total rib number about 110–130 (with about 55–65 ribs in both anterior and posterior zones at adult stages).

Anterior zone with a reticulate sculpture of low, smooth rounded ribs, becoming slightly nodulous where they cross irregularly sinuous and approximately concentric, branched or interrupted fine ridges. Concentric elements tending to be more apparent anteriorly whereas the radial elements become less pronounced. Antero-dorsal margin bevelled and thickened just anterior to umbo, reflected over the corresponding part of the outer shell surface, forming a short and well defined lunular heart, minutely ridged and flattened on top. Lunular sector smooth (apart from growth lines), not clearly demarcated from the surrounding surface, and roughly extending to the level of the anterior lateral teeth.

Posterior sculptural area mainly composed of well developed radial ribs, transverse interstitial bars and numerous spines or tubercles giving this area a distinctly

scabrous aspect. Radial ribs squarish in cross section, as wide as the interstices, the latter becoming a little wider on the posterior slope. Every second to third interstice sculptured with a row of distantly placed, erect, blunt and dorsally notched stout spines occupying the whole width of interstice. Other interstices with well developed crossbars nearly as high as adjacent ribs and numerous small tubercles arising from the posterior ends of crossbars and encroaching upon the anterior side of the adjacent ribs. Radial ribs disappearing toward the postero-dorsal margin of valves which is only sculptured with a few radial rows of spiny tubercles alternatively stronger and smaller; 2 or 3 rows of smaller tubercles usually present between 2 successive rows of larger spines, sometimes intercalated with minute granules. The demarcation line between the anterior and posterior zones displays oblique to radial ribbing extending anteriorly on the ventral margin to at least 3/5 of the adult shell length.

Hinge somewhat arched, with two unequal cardinal teeth in each valve, the more ventral cardinal rather large, prominent and curved, the more dorsal forming a small conical tubercle; cardinal teeth joined by a saddle in the right valve, but separated by a deep socket in the left valve. Posterior lateral teeth farther to cardinals than anterior laterals; left valve with single posterior lateral and single anterior submarginal lateral; right valve with single submarginal posterior and paired anterior laterals separated by a deep socket, with dorsalmost anterior lateral much reduced.

Internal margins with fine crenulations in accordance with the outer radial sculpture, disappearing toward the anterior and posterior ends of the dorsal margin. Protruding elements of these crenulations correspond respectively with radial ribs in the posterior sculptural area of each valve, and with rib interstices in the anterior area.

Exterior and interior of the shell entirely white.

DISTRIBUTION AND ECOLOGY

This species appears to be confined to northwestern Australia, in the Arafura Sea (NT and southern tip of Indonesia) and north of WA (Figure 17E). It is presently known from deep water at the Sahul Shelf edge (depth range 100–218 m) and so far only known from single valves.

REMARKS

This species is characterised by its relatively wide posterior sculptural area, extending to more than 1/2 of the shell length and by the demarcation line between anterior and posterior sculptural areas, featuring markedly oblique to radial sculpture. It appears morphologically very similar to *M. gilchristi* (G.B. Sowerby III, 1904) (Figures 4G–L), but that species has a completely different West Indian Ocean distribution, ranging from South Africa to Mozambique and northern Madagascar. Despite the observed variability of their shells and the absence of entire specimens of *M. scabrosum* in fresh condition, both species can presently be distinguished through features of the posterior sculptural area. In *M. gilchristi*, transverse bars of the rib interstices tend to be rather narrow on the disc and become somewhat thinner to even sub-lamellate on the posterior slope, whereas they are slightly thicker throughout in *M. scabrosum*. In *M. gilchristi*, additional granules of the interstices are smaller, more delicate and easily broken, with a characteristic, somewhat dorso-ventrally compressed and spatula-like shape (Figure 4I). They are usually restricted to the posterior half of the interstices and often more or less expanded into rather thin and rounded flattened processes on the posterior slope (Figure 4K), contrary to *M. scabrosum* where interstitial granules typically have a roughly conical shape (Figures 4D–E), tend to be stronger, and often extending over most of the width of the interstices. *Microcardium scabrosum* and *M. gilchristi* may constitute a pair of sibling species. This could be solved only with additional well preserved Australian material and the possibility of DNA sequencing. *Microcardium tenuilamellosum* Poutiers, 1981, presently known in the West Pacific from the Philippines, Solomon Islands and Vanuatu, also has a wide posterior sculptural area with an oblique anterior limit. However, it differs markedly from the two preceding species by its dense and lamellate transverse sculpture of rib interstices on the posterior slope, by the absence of proliferation of interstitial tubercles in the posterior area and by the indistinct lunular heart.

ETYMOLOGY

The species name alludes to the finely and densely spiked aspect of the posterior half of the shell.

Genus *Pratulum* Iredale, 1924

Pratulum Iredale, 1924: 182, 207 (as a subgenus of *Nemocardium*). Type species by original designation: *Cardium striatulum thetidis* Hedley, 1902; Recent, Australia, New South Wales, off Port Kembla and Cape Three Points.

Pratulum occidentale sp. nov. Poutiers

Figures 5A–F, 6A–M, 17F

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Nemocardium (*Pratulum*) *thetidis* (Hedley, 1902) [*pars*] — Wilson and Stevenson 1977: 69–71.

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia:*** **Zuytdorp**, Off Red Bluff, 24°01.8'S, 113°01.8'E, 100–101 m, 08.12.2005, Leg. S.M. Slack-Smith & M.P. Salotti, CSIRO RV 'Southern Surveyor' Cruise SS1005, Nov/Dec 2005, Stn SS1005/133 (WAM S29307, 1 p.v., A.).

Paratypes

Australia: ***Western Australia:*** **North West Shelf**, approx. 135 miles N.W. of Roebuck Bay, 17°34'S, 120°22'E, 188 m, 30.11.1967, Leg. BMR, MV 'Kos 2', Stn K67-252 (AMS C145.725, 1 s.v., paratype); **Ningaloo**, Off Point Cloates, 22°50.92'S, 113°30.66'E, 100 m, 09.12.2005, Leg. S.M. Slack-Smith & M.P. Salotti, CSIRO RV 'Southern Surveyor' Cruise SS1005 Nov/Dec 2005, Stn SS1005/135 (WAM S29308, 3 p.v., A, paratypes; MNHN-IM-2000-32637, 1 p.v., A, paratype); **Zuytdorp**, Off Red Bluff, 24.03°S, 113.03°E [24°01.8'S, 113°01.8'E], 100–101 m, 08.12.2005, Leg. S.M. Slack-Smith & M.P. Salotti, CSIRO RV 'Southern Surveyor' Cruise SS1005, Nov/Dec 2005, Stn SS1005/133 (WAM S29446, 3 s.v., paratypes); N.W. of Bluff Point, Geraldton, 27°18'S, 113°16'E, 99 m, 09.10.1963. Stn CSIRO DM6/204/63 (WAM S15916, 1 s.v., paratype).

Other material

Australia: ***Western Australia:*** **Oceanic Shoals**, Approx. 170 miles N. of Broome, 15°27'S, 121°31'E, 210 m, 20.11.1967, Leg. BMR, MV 'Kos 2', Stn K67-216 (AMS C145.724, 2 s.v.); N.W. of Cape Leveque, 15°11.1'S, 121°26.9'E to 15°12.9'S, 121°25.7'E, soft bottom, 258–260 m, 17.02.1984, Leg. S. Slack-Smith on FRV 'Soela' Cruise II 1982 (WAM S70659 (ex 258-88), 2 s.v.); Approx. 100 miles N.W. of Broome, 16°58'S, 120°47'E, 194 m, 29.11.1967, Leg. BMR, MV 'Kos 2', Stn K67-248 (AMS C145.722, 18 s.v.); Rowley Shoals, off Mermaid Reef, 17.4872°S, 120.4606°E to 17.4954°S, 120.4679°E [17°29.23'S, 120°27.64'E to 17°29.72'S, 120°28.07'E], 184–187 m, 20.06.2007, Leg. C. Whisson & O. Gomez, CSIRO RV 'Southern Surveyor' Cruise, Stn SS0507/091 (WAM S34674, 3 s.v.); Rowley Shoals, 17°20'S, 119°10'E, 300 m, 20.12.1969, Leg. K. Ozawa, Tokyo University of Fisheries Exped. FV 'Umitaka Maru' 1969, Stn UMD/69/21 (WAM S15914, 1 s.v.); Approx. 230 miles W. of Broome, 18°00'S, 118°56'E, 261 m, 06.11.1967, Leg. BMR, MV 'Espirito Santo', Stn E68-552 (AMS C145.739, 18 s.v.); 130 miles N. of Port Hedland, 18°13'S, 118°37'E, 229 m, 07.11.1968, Leg. BMR, MV 'Espirito Santo', Stn E68-557 (AMS C145.731, 1 s.v.; AMS C145.732, 8 s.v.); Approx. 230 miles W. Roebuck Bay, 18°30'S, 118°03'E, 238 m, 11.10.1968, Leg. BMR, MV 'Espirito Santo', Stn E68-576 (AMS C145.740, 5 s.v.); **North West Shelf**, Approx. 135 miles N.W. of Roebuck Bay, 17°34'S, 120°22'E, 188 m, 30.11.1967, Leg. BMR, MV 'Kos 2', Stn K67-252 (AMS C145.725, 11 s.v.); 106 nautical miles N. of Port Hedland, 18°30.1'S, 118°36.2'E to 18°31.6'S, 118°37'E, bottom with shells, 136–146 m, 02.04.1982, Leg. J. Marshall on FRV 'Soela' Cruise II 1982 (WAM S70654 (ex 257-88), 13 s.v.); 114 nautical miles N. of Port Hedland, 18°25'S, 118°22'E, rubble and grey mud, 200 m, 02.04.1982, Leg. L.M. Marsh on FRV 'Soela' Cruise II 1982 (WAM S70655 (ex 254-88), 10 s.v.; WAM S70657 (ex 256-88), 3 s.v. included 2 fragm.); 114 nautical miles N. of Port Hedland, 18°25'S, 118°22'E, limestone, rubble and grey mud, 201 m, 02.04.1982, Leg. L.M. Marsh on FRV 'Soela' Cruise II 1982 (WAM S70656 (ex 255-88), 2 s.v.); 90 miles N.W. of Port Hedland, 19°07'S, 118°15'E, 88 m, 11.11.1968, Leg. BMR, MV 'Espirito Santo', Stn E68-582 (AMS C145.728, 2 s.v.); 129 nautical miles N.E. of Cape Lambert, 18°38.6'S, 118°07'E, limestone rubble and dead shells, 150 m, 18.08.1995, Leg. L.M. Marsh et al., AIMS Survey RV 'Lady Basten' 1995, Stn AIMS/95/LB5B (WAM S15926, 1 s.v.); Approx. 120 miles N. of Port Hedland, 18°42'S, 118°02'E, 161 m, 25.11.1968, Leg. BMR, MV 'Espirito Santo', Stn E68-708 (AMS C145.727, 4 s.v.); 100 nautical miles N.W. of Port Hedland, 18°47'S, 117°58'E, 154 m, 28.03.1982, Leg. L.M. Marsh, CSIRO FRV 'Soela' Cruise II 1982, Stn SO2/82/10A (WAM S15904, 1 s.v.; WAM S35206, 2 s.v.); 100 nautical miles N.W. of Port Hedland, 18°47'S, 117°58'E, grey mud and shell rubble, 154 m, 28.03.1982, Leg. L.M. Marsh on FRV 'Soela' Cruise II 1982 (WAM S70658 (ex 259-88), 24 s.v.; WAM S70660 (ex 253-88), c. 220 s.v., including fragm.); Off Port Hedland, 18°48'S, 117°57'E, 152 m, 11.1968, Leg. BMR, MV 'Espirito Santo', Stn E68-580 (AMS C145.737, 1 s.v.; AMS C145.738, 2 s.v.); 109 nautical miles N.W. of Port Hedland, 18°56'S, 117°21'E, 201–202 m, 14.04.1982, Leg. L.M. Marsh, CSIRO FRV 'Soela' Cruise II 1982, Stn SO2/82/48 (WAM S57141, 1 s.v.; WAM S57160, 1 s.v.); Approx. 130 miles N.W. of Port Hedland, 19°08'S, 117°12'E, 155 m, 20.10.1968, Leg. BMR, MV 'Espirito Santo', Stn E68-613 (AMS C145.733, 1 s.v.); Approx. 240 miles N.W. of Port Hedland, 19°12'S, 115°57'E, 274 m, 24.11.1968, Leg. BMR, MV 'Espirito Santo', Stn E68-638 (AMS C145.730, 1 s.v.); Approx. 190 miles N.W. of Port Hedland, 19°24'S, 115°52'E, 238 m, 27.11.1968, Leg. BMR, MV 'Espirito Santo', Stn E68-654 (AMS C145.734, 14 s.v.); Approx. 190 miles N.W. of Port Hedland, 19°25'S, 115°51'E, 256 m, 24.11.1968, Leg. BMR, MV 'Espirito Santo', Stn E68-646 (AMS C145.735, 5 s.v.); Approx. 190 miles N.W. of Port Hedland, 19°32'S, 115°49'E, 183 m, 27.11.1968, Leg. BMR, MV 'Espirito Santo', Stn E68-653 (AMS C145.736, 6 s.v.); Approx. 200 miles N.W. of Port Hedland, 19°29'S, 115°38'E, 320 m, 28.11.1968, Leg. BMR, MV 'Espirito Santo', Stn E68-660 (AMS C145.729, 3 s.v.); **Pilbara Offshore**, Off Onslow, 20°12'14.76"S, 115°8'20.75"E to 20°12'8.28"S, 115°8'15.71"E, 100 m, 11.06.2007, Leg. C. Whisson & O. Gomez, CSIRO RV 'Southern Surveyor' Cruise, Stn SS0507/018 (WAM S32785, 1 p.v., A); Off Barrow Island, 20.9847°S, 114.9070°E [20°59.08'S, 114°54.42'E], 100–101 m, 13.12.2005, Leg. S.M. Slack-Smith & M.P. Salotti, CSIRO RV 'Southern Surveyor' Cruise SS1005 Nov/Dec 2005, Stn SS1005/135 (WAM S29311, 1 s.v.); Off Barrow Island, 20°58'51.6"S, 114°43'24.96"E, 205–210 m, 09.06.2007, Leg. C. Whisson & O. Gomez, CSIRO

RV 'Southern Surveyor' Cruise, Stn SS0507/006 (WAM S32880, 2 s.v.); **Ningaloo**, Off North West Cape, on N.W. Shelf slope, 21°32.083'S, 114°07.53'E, 190 m, 25.03.2002, Leg. J. Fromont, L.M. Marsh & P. Alderslade, AIMS North West Cape Survey II 2002, Stn 15 (WAM S15921, 4 s.v.); W. of North West Cape, 21°50'S, 113°46'E, 137 m, 06.10.1963, CSIRO HMAS 'Diamantina' Cruise II 1963, Stn DM6/173/63 (WAM S70649 (ex 199-67), 13 s.v.); Off Ningaloo (South), 22.0795°S, 113.7960°E to 22.0873°S, 113.7940°E [22°04.77'S, 113°47.76'E to 22°05.24'S, 113°47.67'E], 201–206 m, 10.12.2005, Leg. S.M. Slack-Smith, & M.P. Salotti, CSIRO RV 'Southern Surveyor' Cruise SS1005 Nov/Dec 2005, Stn SS1005/146 (WAM S29447, 3 s.v.); Off Point Cloates, 22.8487°S, 113.5110°E [22°50.92'S, 113°30.66'E], 100 m, 09.12.2005, Leg. S.M. Slack-Smith & M.P. Salotti, CSIRO RV 'Southern Surveyor' Cruise SS1005 Nov/Dec 2005, Stn SS1005/135 (WAM S29308, 5 p.v., A); SW of Point Cloates, 23°25'S, 113°14'E, sand & shells, 186.5 m, 07.10.1963, CSIRO HMAS 'Diamantina' Cruise II 1963, Stn DM6/185/63 (WAM S70650 (ex 205-67), 5 s.v.); S.W. of Point Cloates, 23°25'S, 113°14'E, 20 m, 07.10.1963, CSIRO HMAS 'Diamantina' Cruise II 1963, Stn DM6/63/185 (WAM S78332, 1 s.v.); **Zuytdorp**, Off Red Bluff, 24.03°S, 113.03°E [24°01.8'S, 113°01.8'E], 100–101 m, 08.12.2005, Leg. S.M. Slack-Smith & M.P. Salotti, CSIRO RV 'Southern Surveyor' Cruise SS1005, Nov/Dec 2005, Stn SS1005/133 (WAM S29307, 41 s.v., 1 p.v., A; WAM S29445, 1 s.v.; WAM S29446, 39 s.v.); Off Red Bluff, 24.0437°S, 113.0270°E [24°02.62'S, 113°01.62'E], 100 m, 08.12.2005, Leg. S.M. Slack-Smith & M.P. Salotti, CSIRO RV 'Southern Surveyor' Cruise SS1005 Nov/Dec 2005, Stn SS1005/126 (WAM S29442, 5 s.v.); N.W. of Carnarvon, 24°31'S, 112°41'E, sand & shells, 111.5 m, CSIRO HMAS 'Diamantina' Cruise II 1963, Stn DM6/194/63, 08.10.1963 (WAM S70651 (ex 206-67), 3 s.v.); Off Carnarvon, 24.6194°S, 112.6660°E [24°37.16'S, 112°39.98'E], 100 m, 07.12.2005, Leg. S.M. Slack-Smith & M.P. Salotti, CSIRO RV 'Southern Surveyor' Cruise SS1005 Nov/Dec 2005, Stn SS1005/120 (WAM S29440, 1 s.v.); W. of Dirk Hartog Island, 25°30'S, 112°22'E, mud, clay & shells, 142.5 m, 08.10.1963, CSIRO HMAS 'Diamantina' Cruise II 1963, Stn 198 (WAM S70652 (ex 207-67), 3 s.v.); W. of Dirk Hartog Island, 25.9076°S, 112.8230°E [25°54.46'S, 112°49.38'E], 100 m, 06.12.2005, Leg. S.M. Slack-Smith & M.P. Salotti, CSIRO RV 'Southern Surveyor' Cruise SS1005 Nov/Dec 2005, Stn SS1005/112 (WAM S25819, 5 s.v.; WAM S29389, 1 s.v.); N.W. of Bluff Point, Geraldton, 27°18'S, 113°16'E, 99 m, 09.10.1963. Stn CSIRO DM6/204/63 (WAM S15916, 1 s.v.); N.W. of Bluff Point, 27°18'S, 113°16'E, bottom with sponge, seastar & oxystomata, 99 m, 09.10.1963, CSIRO Stn DM6/204/63 (WAM S70653 (ex 1043-66), 44 s.v.).

DESCRIPTION

Shell equivalve, inflated and subequilateral, about as high as long, subquadrate ovate in outline and rather small for the genus (up to 12.1 mm long). Umbones prosogyrate, usually positioned just anterior to the mid-length of the shell. The dorsal margin is slightly more oblique anteriorly than posteriorly. Posterior margin nearly straight, forming a rounded angle with the ventral margin, becoming dorsally more convex and oblique to the posterior dorsal margin.

Outer sculpture rather coarse and heterogeneous, changing abruptly on the posterior area of the valves. Radial ribs small and numerous (from 64 to 90, mean 77), well developed over most of the outer surface. Limit between the two zones of sculpture not cutting obliquely, radial ribbing on major part of shell height, and then relative width of both types of sculpture remaining constant during ontogeny.

Anterior and median sculptural zones with many radial ribs (from 39 to 55, mean 49) and slightly wider and low interstices. Ribs well-marked and rounded but relatively low and crossed by numerous, branched or interrupted, approximately commarginal and anastomosing undulating ridges. These tend to form a slightly nodulous reticulate pattern with small tubercles towards the anterior side of the valves. Antero-dorsal margin of the valves raised and somewhat thickened anterior to the umbones, forming a slightly inequivalve, narrow lanceolate process. Lunular sector poorly defined and nearly smooth.

Posterior sculptural area extending over a quarter of the valve surface, with about 28 radial ribs (from 26 to 31) and numerous, often well developed spines. Ribs thinner than in median area, with steeper sides and deeper, larger interstices, progressively weakening toward the Postero-dorsal margin, each bearing on top a row of rather strong and protruding tubercles or spines. Spine insertion on ribs more or less anterior, often markedly encroaching on the anterior side of the rib and inside the interstice, forming somewhat oblique transverse bulgings superficially looking like low 'cross bars' when spines are completely worn off. Rows of spines often alternately larger and smaller on the posterior area; spine shape variable, somewhat laterally compressed or rounder, often more or less concave dorsally. Postero-dorsal margin somewhat depressed in the left valve, more convex in the right valve, forming a tooth-like thickening that overhangs the margin of the left valve.

Periostracum thin and translucent, fibrous toward the periphery of the valves and on the posterior zone where it tends to form irregular threads and simulates a thin commarginal sculpture.

Hinge of each valve with two unequal cardinal teeth, the more ventral cardinal much larger, prominent and curved, the more dorsal forming a small tubercle;

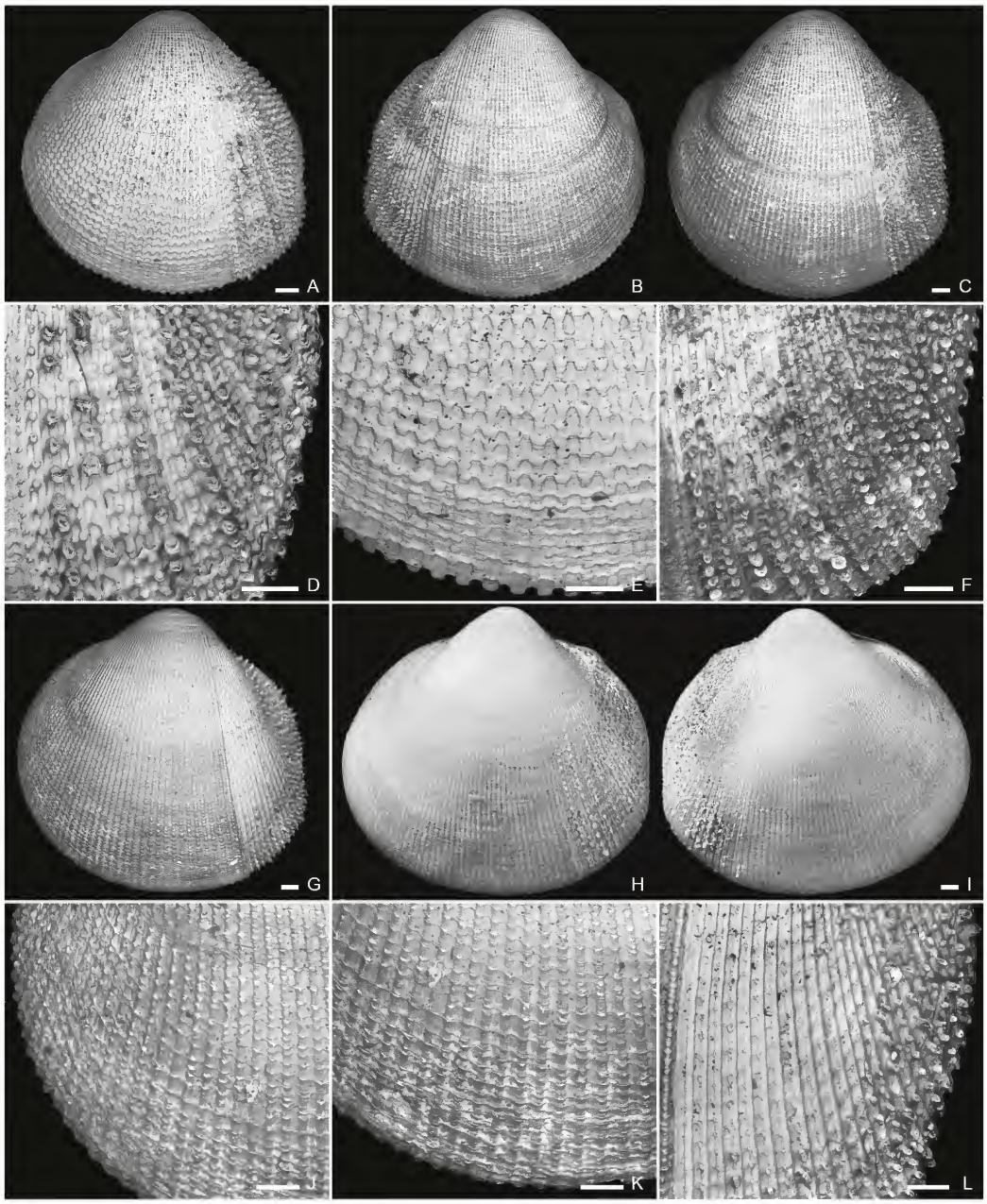

FIGURE 5 A, B, C, D, E, F, *Pratulum occidentale* sp. nov. A, D–E, N.W. of Port Hedland, WA: AMS C145.728, L 7.4 mm; A exterior of l.v., D posterior sculpture, E anterior sculpture; B–C,F, Off Point Cloates, WA: WAM S29308, paratype, L 9.9 mm; B exterior of r.v., C exterior of l.v., F posterior sculpture.

G, H, I, J, K, L, *Pratulum thetidis* (Hedley, 1902). G, J–L, Western Port Bay, Victoria: MNHN-IM-2014-6070, L 11.0 mm; G exterior of r.v., J anterior slope, K median part of anterior sculpture, L posterior sculpture; H–I, Off Perth, WA: WAM S29300, L 8.5 mm; H exterior of r.v., I exterior of l.v. Scale bars: 0.5 mm.

cardinal teeth joined by a thin saddle in the right valve, separated by a deep socket in the left valve. Posterior lateral teeth farther to cardinals than anterior laterals; left valve with single posterior lateral and single anterior submarginal lateral; right valve with single submarginal posterior lateral and paired anterior laterals separated by a deep socket, with most dorsal anterior lateral much reduced.

Internal margins with fine and regular crenulations in accordance with the outer radial sculpture, disappearing toward the dorsal ends of the anterior and posterior margins. Protruding elements of crenulations corresponding respectively with radial ribs in the posterior sculptural area, and with rib interstices in the anterior area.

Shell white, often light pinkish orange on posterior zone, umbonal area and antero-dorsal margin, sometimes with two short rays of orange on umbo and pale pinkish banding.

DISTRIBUTION AND ECOLOGY

An endemic tropical WA species (Figure 17F) found from 20–320 metres deep, living in 100–101 metres depth.

REMARKS

Pratulum thetidis (Figures 3N–P, 5G–L), an endemic South and East Australian species mainly confined to temperate waters, differs from *P. occidentale* sp. nov. by its relatively larger size (largest specimen measured 18.0 mm long), by being relatively less high and less inflated, by the finer nature of the sculpturing with much finer anastomosed commarginal threads of anterior and median areas, and rather small spines of posterior area, making the sculptural heterogeneity usually rather discreet to the naked eye. The coarser sculpture and strong heterogeneity between the two sculptural zones of the new species bear a superficial resemblance to the sculpture of *Microcardium*. However, diagnostic sculptural patterns of rib interstices in *Microcardium* (with rows of spines alternating with rows of cross-bars or transverse lamellae, as high as or higher than ribs) never occur in *P. occidentale* sp. nov. All spines are distinctly related to radial ribs, and the low 'transverse' sculpture of interstices merely correspond to basal bulging of the spines arising along the anterior side of the ribs. *Pratulum occidentale* and *P. thetidis* seem to be strictly allopatric in WA (Figure 17F), with the area between Shark Bay and the Houtman Abrolhos Islands as a mutual border (S. end of range and N. end of range, respectively).

ETYMOLOGY

Compared to the two other *Pratulum* species from temperate environments (*P. pulchellum* (Gray in Dieffenbach, 1843) in New Zealand, and the nearby *P. thetidis* (Hedley, 1902) in Southern Australia), *P. occidentale* has a more westerly distribution in subtropical waters of WA, as suggested by its species name.

Genus *Trifaricardium* Kuroda & Habe, 1951

Trifaricardium Kuroda & Habe in Kuroda, 1951: 86 (*nomen nudum*).

Trifaricardium Kuroda & Habe in Habe, 1951: 152–153, fig. 328. Type species by monotypy: *Trifaricardium nomurai* Kuroda & Habe in Kuroda, 1951; Recent, Japan.

Trifaricardium morrisoni ter Poorten & Huber, 2007

Figures 6N–R, 17G

Trifaricardium morrisoni ter Poorten & Huber, 2007: 71–74, figs 5–9.

MATERIAL EXAMINED

Australia: ***Western Australia:*** **Oceanic Shoals**, N.W. of Cape Leveque, 14°52.2'S, 121°41.7'E to 14°53.7'S, 121°39.9'E, 220–224 m, Engel trawl on soft bottom, 16.02.1984. Leg. S.M. Slack-Smith, Stn SO1/84/085 (paratype, WAM S15911, 1 s.v.); W.N.W. of Lacepede Archipelago, 15°57.2'S, 120°46.2'E to 15°59.05'S, 120°44.6'E, 296–298 m, Engel trawl on soft bottom, 10.02.1984. Leg. S.M. Slack-Smith, Stn SO1/84/055 (paratype, WAM S15908, 1 s.v.); Rowley Shoals, 17°20'S, 119°10'E, 300 m, 20.12.1969. Leg. K. Ozawa, Tokyo Univeristy of Fisheries Exped. FV 'Umitaka Maru', Stn UMD/69/21 (holotype, WAM S29458, 1 s.v.; paratypes WAM S15912, 13 s.v.; paratypes ZMA.MOLL.139454, 4 s.v.); **North West Shelf**, 100 nautical miles N.W. of Port Hedland, 18°47'S, 117°58'E, 154 m, triangular dredge, grey mud and shell rubble, 28.03.1982. Leg. L.M. Marsh, Stn SO2/82/10A (paratype, WAM S15903, 1 s.v.).

DESCRIPTION

Shell relatively small (L 10–12 mm), thin, rounded, length slightly exceeding height. Nearly equilateral with postero-dorsal margin slightly truncated. Outer surface with heterogeneous rib structure, divided into two very differently sculptured and unequally sized zones. Posterior zone very large, comprising approximately 95 fine thread-like radial ribs. Interstices punctuated; every second, third or fourth carrying small but erect, blunt spinelets, hollowed dorsally. Occasionally, a secondary row of spinelets can be present. Towards the posterior slope, punctuations in the interstices becoming progressively of a more laminate nature and consisting of densely placed laminae. Ornamentation abruptly

changing into a strongly different morphology towards the anterior slope, with numerous very fine, slightly undulating commarginal threads, crossed by highly weakened, unsculptured radial riblets. Lunule smooth, not well delimited; lunular heart poorly defined, margins raised and thickened on both valves. External and internal colour uniformly white.

DISTRIBUTION AND ECOLOGY

This species is so far only known from the type material and confined to the outer edge of the continental shelf of northern WA (Figure 17G), found in deep water from 154–300 metres (based on single valves). Given these oceanic tropical records, an endemic WA occurrence does not seem likely, and it may be predicted that the true distribution range will cover parts of the Central IWP as well.

REMARKS

Poutiers (1992: 142, fig. 2M) mentions an as yet undescribed but closely related *Trifaricardium* species from QLD, represented in the WAM collections by three valves (WAM S78148), originating from East of Caloundra Island, taken at a depth of 65–75 fms (119–137 metres). It differs from *T. morrisoni* by its greater number of sculptured radial rows, which are also coarser.

Trifaricardium nomurai Kuroda & Habe, 1951

Figures 6S–U

Cardium (*Acanthocardia*) *cancellatum* Nomura, 1933: 81–82, pl. 3 figs 9a–b (*non* Gmelin, 1791).

Trifaricardium nomurai Kuroda & Habe in Kuroda, 1951: 86.

Trifaricardium nomurai Kuroda & Habe in Kuroda, 1951 — ter Poorten 2009: pl. 20 fig. 12, pl. 22 figs 6–9; Huber 2010: 307, fig., ter Poorten 2011: pl. 1111 figs 5–6.

MATERIAL EXAMINED

Australia: ***Western Australia:*** **Oceanic Shoals**, Rowley Shoals, 17°20'S, 119°10'E, 300 m, 20.12.1969. Leg. K. Ozawa, Tokyo University of Fisheries Exped. FV 'Umitaka Maru', Stn UMD/69/21 (WAM S29459, 1 s.v.); Rowley Shoals, 17°20'S, 119°10'E, 260 m, 20.12.1969. Leg. K. Ozawa, Tokyo Univerisity of Fisheries Exped. FV 'Umitaka Maru', Stn UMD/69/20 (WAM S39961, 1 s.v.).

DESCRIPTION

Shell medium sized (H 20–23 mm), rather solid, inflated, roughly quadrangular with rounded anterior and ventral margins and slightly truncated posterior margin. Heterogeneous rib structure, surface divided into two very differently sculptured and unequally sized zones, in total between 110–120 minute radial ribs. Anterior zone covering less than a quarter of the shell, having low and unsculptured rounded radial ribs, crossed by coarse, strongly undulating, anastomose commarginal threads. Posterior zone covering more than three-quarters of the shell; interstices of this zone with transverse bars, every second to fourth bearing small, blunt spinelets. Lunular area vaguely bordered, generally smooth; lunular heart a simple ovate and rounded bulge of the dorsal margin, slightly larger on right valve. Shell exterior and interior entirely white, sometimes with a slight hue of lemon-yellow on the posterior slope.

DISTRIBUTION AND ECOLOGY

In WA only known from two worn samples, found in deep water off Rowley Shoals (single valves, depth range 260–300 metres). Until recently this species was only known from Japan and the South China Sea. Ter Poorten and Huber (2007) have shown that it has a much larger distribution than currently known, encompassing the Philippines to offshore in northern WA. Additionally, material from Papua New Guinea has become known (New Ireland, MNHN, det. TP).

REMARKS

The very limited material available suggests a comparable WA geographic and bathymetrical distribution to that of *Trifaricardium morrisoni*. Recent phylogenetic work places *T. nomurai* in a clade with seven *Microcardium* species (Herrera et al. 2015). This casts doubt on the generic status of *Trifaricardium*. Additional DNA analyses based on more material, including *Microcardium peramabile* (Dall, 1881), the type species of *Microcardium*, will be needed to clarify this finding.

Subfamily 'Orthocardiinae' Schneider, 2002

REMARKS

The genera *Lyrocardium* and *Afrocardium* reported herein have previously been assigned to Laevicardiinae (Schneider 1995) and Orthocardiinae (Schneider 2002) respectively. *Cardium victor* Angas, 1872 (Table 1) has been transferred to *Freneixicardia* by ter Poorten (2009), a genus that was also assigned to Orthocardiinae (Schneider 2002). All three genera are grouped in clade B-1 of Herrera et al. (2015) with *Lyrocardium* not closely related to any other genus belonging to Laevicardiinae. Although, awaiting additional combined molecular and morphological research, Orthocardiinae is tentatively applied for the genera in this clade.

FIGURE 6 A, B, C, D, E, F, G, H, I, J, K, L, M, *Pratulum occidentale* sp. nov. A–B, N. of Bluff Point, WA: WAM S15916, paratype, length 9.0 mm. A, exterior of r.v., B, interior of r.v.; C–D, off Red Bluff, WA: WAM S29445, length 10.0 mm. C, exterior of l.v., D, interior of l.v.; E–I, off Red Bluff, WA: WAM S29307, holotype, length 5.6 mm. E, exterior of l.v., F, exterior of r.v., G–I, dorsal under slightly different light conditions and angles; J–M, off Red Bluff, WA: WAM S29446, paratypes, J–K, length 7.7 mm, J, interior of r.v., K, exterior of r.v., L, length 7.3 mm, exterior of l.v., M, length 6.6 mm, exterior of r.v.

N, O, P, Q, R, *Trifaricardium morrisoni* ter Poorten & Huber, 2007. S. of Rowley Shoals, WA. N–O, WAM S29458, holotype, length 11.9 mm. N, exterior of r.v., O, interior of r.v., P–Q, ZMA.MOLL.139454, paratypes. P–Q, length 11.1 mm, P, anterior of l.v., Q, exterior of l.v., R, length 10.5 mm, exterior of l.v.

S, T, U, *Trifaricardium nomurai* Kuroda & Habe, 1951. S. of Rowley Shoals, WA. S, WAM S29459, height 16.0 mm (fragm.), anterior of l.v.; T–U, WAM S39961, height 17.2 mm (defect), T, exterior of l.v., U, interior of l.v.

Genus *Afrocardium* Tomlin, 1931

Afrocardium Tomlin, 1931: 449–450 (as a subgenus of *Fragum*). Type species by original designation: *Fragum* (*Afrocardium*) *shepstonense* Tomlin, 1931; Recent, Port Shepstone, Kwazulu Natal, South Africa.

Afrocardium richardi (Audouin, 1826)

Figures 7A–I, 19A

Cardium richardi Audouin, 1826: 51.

Cardium carditaeforme Reeve, 1845: sp. 127, pl. 22 fig. 127.

Cardium arabicus Issel, 1869: 77.

Cardium skeeti Hedley, 1906: 476, pl. 38 fig. 25.

Cardium (*Fragum*) *crenelloides* Melvill, 1909: 75, 134, pl. 5 fig. 13.

Cardium (*Fragum*) *roseolum* Melvill, 1909: 134, pl. 5 fig. 14.

Cardium (*Fragum*) *rubescens* E.A. Smith, 1911: 317–318, fig.

Cardium euglyptum G.B. Sowerby III, 1914: 480, pl. 19 fig. 14.

Cardium ebaranum Yokoyama, 1927: 430–431, pl. 48 fig. 15.

Afrocardium skeeti (Hedley, 1906) — Lamprell and Whitehead 1992: pl. 32 fig. 215.

Afrocardium richardi (Audouin, 1826) — ter Poorten 2009: pl. 5 fig. 6, pl. 6 figs 6–10; Huber 2010: 291, fig., ter Poorten 2011: pl. 1091 figs 2–6.

MATERIAL EXAMINED

Australia: ***Northern Territory:*** **Arnhem Wessel**, central Arnhem Land, 17 nautical miles NNW. f Cape Stewart, wreck of M.V. "SANYO MARU", 11°41.48'S, 134°36.71'E, 23 m, 20.04.2002. Leg. R.C. Willan (NTM P.19940, 1 p.v., A); Timor Sea, rocky shoal 30 km due W. of Bathurst Island, 11°39'S, 129°48'E, 25 m, 10.1993. Leg. I.A. Knuckey (NTM P.8217, 7 p.v., A); 90 nautical miles west of Darwin, western end of Flat Top Bank, 12°16.8'S, 129°14'E, 31 m, 17.05.1992. Leg. R.C. Willan (NTM P.37662, 5 s.v.).

Australia: ***Western Australia:*** **North West Shelf**, W. of Broome, 17°58'S, 122°14'E (Egaz), 90 m, 21.12.1969. Leg. K. Ozawa, Tokyo Uni of Fisheries Exped. FV 'Umataka Maru' 1969, Stn UMD6927 (WAM S57165, 1 s.v.); **Ningaloo**, W. of North West Cape, 21°50'S, 113°46'E, 75 fms (137 m), 06.10.1963. CSIRO HMAS 'Diamantina' Cruise II 1963, Stn DM6/173/63 (WAM S15920, 1 s.v.).

Literature records

ALA / OZCAM: Circa 140 miles N. of Cape Leveque, 12.11.1967 (AMS C.451405, det. J. Schneider).

DESCRIPTION

Shell small to medium (L 10–20 mm), thin shelled, outline highly variable, from submodioliform to oblique quadrangular, strongly inequilateral with beaks towards the anterior and occasionally a slight concave ventral margin. Posterior margin markedly digitate. Between 36–43 low radial ribs, slightly concave with a central groove; in early juveniles of alternating width. Ribs heavily ornamented with often irregular, close-set squamose scales, posteriorly short spinose. Interstices with commarginal striae. Hinge line long and bent with posterior laterals far from cardinal teeth. Exterior colours extremely variable: often various shades of red-brown, orange, pink, lemon, purple, in the majority with darker streaks posteriorly. Interior colours similarly variable.

DISTRIBUTION AND ECOLOGY

Both WA records of this species come from deeper water (90–137 meters depth) and originate from the northern part of the state (Figure 19A), in agreement with the wide tropical Indo-West Pacific distribution of the species. *Afrocardium richardi* has been found alive nestling in a crevice within a block of living coral on a rocky reef (QLD, NTM P.40393) and attached to a nylon monofilament net inside pearl oyster spat-collecting bags, suspended 5 metres above clean sand substrate with sparse encrusting fauna (NT, NTM P.8217). Both records add further evidence to its expected epifaunal nestling habit, very much like that of the shallow water photosymbiotic fragine, *Fragum mundum*.

REMARKS

Cardium skeeti Hedley, 1906, described from QLD (Masthead Island), is considered a junior synonym of *A. richardi*. It was reported 'an abundant species in 17–20 fathoms' (Hedley 1906: 476). Hedley's syntypes, present in AMS C18858 (Hylleberg 2004: 918, fig.), NMW 1955.158.1237 (Meechan 1987) MNHN IM-2014-5514 (10 valves, examined by the first author, Figures 7G–I), NHMUK 1908.7.7.107-110 (four valves, examined by the authors, Figures 7E–F), USNM 201420 (five valves, examined by the first author) and ANSP 94824 (four valves, examined by the first author), show a large intraspecific variability, mainly affecting shell shape and colouration but not rib number and sculpture, due to the cryptic epifaunal life habit often referred to as nestling (and utilizing byssal attachment) (ter Poorten

FIGURE 7 A, B, C, D, E, F, G, H, I, *Afrocardium richardi* (Audouin, 1826). A–B, W off North West Cape, WA: WAM S15920, length 7.2 mm. A, exterior of r.v., B, interior of r.v.; C–D, W of Broome, WA: S57165, length 8.6 mm (defect). C, exterior of l.v., D, interior of l.v.; E–I, Syntypes of *Cardium skeeti* Hedley, 1906, Masthead Island, QLD. E–F, NHMUK 1908.7.7.107-110, E, length 4.7 mm, exterior of r.v., F, length 4.5 mm, exterior of l.v., G–I, MNHN IM-2014-5524, exterior of r.v., G, length 4.1 mm, H, length 5.6 mm, I, length 4.5 mm.

J, K, L, M, *Lyrocardium aurantiacum* (A. Adams & Reeve, 1850). J–K, Ningaloo Marine Park, WA: WAM S78130, length 34.5 mm. J, exterior of r.v., K, interior of r.v.; L–M, N. of Rosemary Island, WA: WAM S78055, length 29.4 mm. L, exterior of l.v., M, interior of l.v.

N, O, P, Q, R, S, T, U, *'Laevicardium' lobulatum* (Deshayes, 1855). N–Q, Clerke Reef, WA: WAM S68164, height 9.8 mm; N, exterior of r.v., O, exterior of l.v., P, interior of r.v., Q, interior of l.v.; R–U, Negros Island, Philippines: NHMUK 1974135, syntypes. R–S, height 22.4 mm, R, interior of r.v., S, exterior of l.v., T, height 19.6 mm, exterior of l.v., U, height 20.1 mm, exterior of l.v.

2009). The same is the case for *Cardium rubescens* E.A. Smith, 1911, described from Christmas Island (NHMUK 1911.2.26-14-15, two syntypes, examined by the authors). With most specimens remaining much smaller than 10 mm, and the vast majority of the faunal surveys undertaken in WA to date focussing on macromolluscs, it is likely that this species is more common on the shelf of northern WA than is presently known.

Genus *Lyrocardium* Meek, 1876

Lyrocardium Meek, 1876: 167 (as a subgenus of *Laevicardium*). Type species by subsequent designation (Dall, 1900: 1076): *Cardium lyratum* G.B. Sowerby II, 1840; Recent, Philippines, S.E. Negros, Dumaguette.

Amphicardium von Martens in Möbius, Richters & von Martens, 1880: 324 (as a subgenus of *Cardium*). Type species by subsequent designation (Keen, 1937: 4–5): *Cardium lyratum* G.B. Sowerby II, 1840.

Divergicardium Dunker, 1882: 212 (as a subgenus of *Cardium*). Type species by subsequent designation: *Cardium lyratum* G.B. Sowerby II, 1840.

Lyrocardium aurantiacum (A. Adams & Reeve, 1850)

Figures 7J–M, 19B

Cardium aurantiacum A. Adams & Reeve, 1850: 77, pl. 22 fig. 4.

Lyrocardium aurantiacum (A. Adams & Reeve, 1850) — Huber 2010: 306, fig.; ter Poorten 2011: pl. 1115 figs 3–4.

Not: *Nemocardium* (*Lyrocardium*) *aurantiacum* (Adams & Reeve, 1850) — Lamprell and Healy 1998: 244, fig. 740 (= *L. lyratum*).

MATERIAL EXAMINED

Australia: ***Western Australia:*** **North West Shelf**, Dampier Archipelago, 33 nautical miles N. of Rosemary Island, 19°55'S, 116°36'E, 58 m, 29.09.1982. Leg. L.M. Marsh (WAM S78055, 1 s.v.); **Pilbara Offshore**, Off Onslow L19, 20°12'14.76"S, 115°8'20.75"E to 20°12'8.28"S, 115°8'15.71"E, 100 m, 11.06.2007. Leg. C. Whisson, CSIRO RV 'Southern Surveyor' Cruise, Stn SS0507/018 (WAM S32871, 1 s.v.); Murion Islands, S. Muiron Island, off N.W. coast, 21°39.81'S, 114°20.15'E, 12–15 m, 15.08.1995. Leg. S.M. Slack-Smith et al., WAM Muiron Islands Exped. 1995, Stn 1 (WAM S78131, 1 s.v.); **Ningaloo**, Mandu Creek, 22°6'30"S, 113°50'43"E to 22°6'26"S, 113°50'43"E, 73 m, 16.08.2008. Leg. O. Gomez & J. Colquhoun, AIMS-WAM RV 'Cape Ferguson' Ningaloo Survey IV 08/09.2008, Stn SOL4769/2008/1-005SL02 (WAM S78130, 1 s.v.); Ningaloo Marine Park, off Osprey Sanctuary Zone, 22°18.263'S, 113°46.544'E to 22°18.505'S, 113°46.157'E, 55 m, 25.04.2006. Leg. M.P. Salotti, AIMS-WAM RV 'Cape Ferguson' Ningaloo Survey I, Stn CF4010&11/2006/D005 (WAM S78132, 1 s.v.)

DESCRIPTION

Shell medium sized (L 30–45 mm), rather thin, slightly inequilateral, obliquely rounded and rather inflated. Shell surface glossy. Margins rounded, central part of posterior margin almost straight. Margins finely crenulate, posterior margin smooth. Anterior part covered with widely spaced oblique ridges, median part with very faint radial riblets, posterior part smooth. Lunular heart with well raised dorsal margin, thickened on both valves. Exterior colour cream or with orange streaks and zigzag patterns, darker on posterior slope. Lunule and escutcheon pink or purple. Interior cream, pink or yellowish with darker posterior zone and umbonal cavity.

DISTRIBUTION AND ECOLOGY

The presence of *L. aurantiacum* in northern WA waters is confirmed by several specimens, all dead collected in 12–100 metres depth. All WA material has been found in a relatively small area off the Pilbara and Ningaloo coasts (Figure 19B), adding to the relatively high bivalve diversity in the Pilbara (Wilson 2013: table 8.4). Its presence in QLD is confirmed by several samples (NTM and TP). It is widely distributed in the Central IWP. The few available live records are from a depth range of 10–30 metres.

REMARKS

Wilson and Stevenson (1977) were well aware of the existence of this species, but at that time (mid 1970s) had only Indonesian material in the WAM collections at their disposal. The specimen figured by Lamprell and Healy (1998: fig. 740) refers to *L. lyratum* from Exmouth Gulf and is in the reference collection of the first author (TP 1461).

Subfamily Fraginae Keen, 1951

REMARKS

Clade C of Herrera et al. (2015) contains subclade 4 with *Fragum*, *Corculum* and *Lunulicardia* as well as *Microfragum erugatum*; whereas the type species of *Microfragum* (*Cardium festivum*) is placed in subclade 3, together with *Ctenocardia* and several American genera (*Trigoniocardia*, *Apiocardia* and *Americardia*). In the present study, *M. erugatum* is placed in *Fragum* (see above, under 'Comments on Wilson and Stevenson (1977) taxa').

Genus *Corculum* Röding, 1798

Corculum Röding, 1798: 188. Type species by subsequent designation (von Martens, 1870: 586): *Cardium cardissa* Linnaeus, 1758; Recent, 'O. Asiatico' (Indo-West Pacific).

Cardissa Megerle von Mühlfeld, 1811: 52. Type species by monotypy: *Cardissa alba* Megerle von Mühlfeld, 1811; Recent (type locality not mentioned).

Hemicardium Schweigger, 1820: 707. Type species by original designation: *Cardium cardissa* Linnaeus, 1758.

Cardissa Swainson, 1840: 373. Type species by monotypy: *Cardissa spinosa* Swainson, 1840; Recent (type locality not mentioned).

Corculum cardissa (Linnaeus, 1758)

Figures 9M–T, 18A

Cardium cardissa Linnaeus, 1758: 678.

Cardium dionaeum Broderip & G.B. Sowerby I, 1829: 367.

Cardium unimaculatum G.B. Sowerby I in Broderip & G.B. Sowerby I, 1833: 84–85.

Cardium productum Deshayes, 1855: 333 (*non* J. Sowerby in Sedgwick & Murchison, 1835).

Corculum kirai Shikama, 1964: 75, figs 137 (15, 16), 138 (8).

Corculum dionaeum (Broderip & Sowerby, 1829) — Lamprell and Whitehead 1992: pl. 31 fig. 209.

Corculum cardissa (Linnaeus, 1758) — ter Poorten 2009: pl. 10 figs 1–3; Huber 2010: 299, fig.; ter Poorten 2011: pl. 1099 figs 1–7, pl. 1100 figs 1–8.

MATERIAL EXAMINED

Australia: ***Western Australia:*** **Oceanic Shoals**, Cartier Reef, 12°31.8'S, 123°33.3'E, found on strand line of small sand cay, 05.05.1992. Leg. R.C. Willan (NTM P.222, 11 s.v.); Rowley Shoals, Mermaid Reef, W. side, 17°04'42"S, 119°36'07"E, 0 m, 26.07.1982. Leg. WA Museum Party, WAM Rowley Shoals Exped. 1982, Stn 10 (WAM S39933, 1 s.v.); Clerke Reef, 17°16'26"S, 119°21'34"E, 0 m, 22.07.1982. Leg. WA Museum Party, WAM Rowley Shoals Exped. 1982, Stn 15 (WAM S39932, 3 s.v.); S.W. end, 17°22'28"S, 119°20'34"E, 1 m, 24.07.1982. Leg. WA Museum Party, WAM Rowley Shoals Exped. 1982, Stn F (WAM S39931, 1 s.v.); 17°09'35.169"S, 119°13'00.414"E, 0–3 m, 03.10.2014. Leg. C. Bryce, Woodside Kimberley Survey 2014, Stn Bedwell Is Shallow/K14 (WAM S95391, 2 s.v.); E. reef S. of channels, 17°20'S, 119°10'E (WAM S39934, 1 s.v.); Clerke Reef, unknown lat./long., 03.10.2014. Leg. C. Bryce, Woodside Kimberley Survey 2014, Stn Bedwell Is/K14 (WAM S95388, 3 s.v.); Imperieuse Reef, 17°30'32.938"S, 118°57'47.368"E, 15 m, 06.10.2014. Leg. C. Bryce, Woodside Kimberley Survey 2014, Stn 160/K14 (WAM S68263, 2 p.v., A); 17°30'20.627"S, 118°57'45.802"E, 0 m, 09.10.2014. Leg. C. Bryce, Woodside Kimberley Survey 2014, Stn 166/K14 (WAM S68277, 1 p.v., A).

DESCRIPTION

Shell medium to large (H 35–70 mm), rather thin and glassy, inequilateral with anterior slope more expanded than posterior which becomes ventrally concave; shell tumid and excessively flattened, extremely reduced in length; presence of an acute, ridged to spinose radial keel; in anterior and posterior views the shell looks like a stylised heart. Between 12–18 flattened radial ribs on each slope, bearing tubercles, sometimes slightly ridged; interstices smooth. Antero-dorsal margin not touching umbo, slightly depressed in front of it; posterior part of hinge with an extremely short nymphal plate and ligament, but a long escutcheon zone. Colour extremely variable: white, lemon-yellow, pink, orange, brown, sometimes with radially aligned purple stripes on the lighter background.

DISTRIBUTION AND ECOLOGY

So far exclusively reported from the oceanic emergent reefs of northern WA where it was found in shallow water or intertidally (Wells and Slack-Smith 1986; Willan 2005; Figure 18A). *Corculum cardissa* is a somewhat uncommon and cryptic species of the northern oceanic shoals, found in the shallow intertidal of clear, rubbly coral reef habitats. This species has been reported from QLD (Lamprell and Whitehead 1992) but not in NT. It has a wide distribution in the IWP.

REMARKS

The shell morphology of the WAM specimens, many are juveniles, is in agreement with *C. cardissa*, under study at the WAM to test species boundaries (ter Poorten 2009; Huber 2013). It is a member of the photosymbiotic fragines, a wholly photosymbiotic lineage of cardiids (Kirkendale and Paulay 2017). However, unlike many other closely related photosymbiotic species, *C. cardissa* is essentially a dorsoventrally flattened 'living' solar panel with transparent shell microstructural windows that facilitate light penetration through the shell (Carter and Schneider 1997).

FIGURE 8 A, B, C, D, E, F, G, H, I, J, K, L, *Ctenocardia pilbaraensis* sp. nov. A–G, near Onslow, WA: WAM S78025, holotype, length 19.8 mm. A, exterior of l.v., B, exterior of r.v., C, interior of l.v., D, interior of r.v., E, dorsal, F, asymmetrical lunular area, G, anterior slope of l.v.; H–J, off Onslow, WA: TP 4412, paratype, length 28.6 mm. H, exterior of r.v., I, exterior of l.v., J, interior of r.v.; K, Dampier Arch., WA: WAM S22828, paratype, length 19.5 mm, exterior of l.v.; L, 'N. Sabah, Malaysia': TP 3286, height 23.6 mm, exterior of l.v.

M, N, O, P, Q, R, S, T, *Ctenocardia fornicata* (G.B. Sowerby II, 1840). M–O, unknown provenance: NHMUK 1996513, largest of the four possible syntypes, height 26.7 mm. M, exterior of l.v., N, symmetrical lunular area, O, anterior slope of l.v.; P–T, Scott Reef, WA: WAM S39930, length 15.3 mm. P, exterior of r.v., Q, exterior of l.v., R, dorsal, S, interior of r.v., T, interior of l.v. Scale bars: 1 mm.

Genus *Ctenocardia* H. Adams & A. Adams, 1857

Ctenocardia H. Adams & A. Adams, 1857: 459 (as a subgenus of *Hemicardia*). Type species by subsequent designation (Dall, 1900: 1075): *Cardium hystrix* Reeve, 1844 (*non* Lightfoot, 1786) [= *Fragum* (*Ctenocardia*) *symbolicum* Iredale, 1929; *nom. nov.* for *Cardium hystrix* Reeve, 1844]; Recent, Corrigidor Isl., Philippines, c. 7 fms [13 m].

Ctenocardia fornicata (G.B. Sowerby II, 1840)

Figures 8M–T

Cardium fornicatum G.B. Sowerby II, 1840a: figs 50, 50a; 1840b: 7, sp. 84; 1841: 110.

Cardium adamsii Reeve in A. Adams & Reeve, 1850: 77, pl. 22 fig. 2.

Ctenocardia (*Ctenocardia*) *fornicata* (Sowerby, 1840) — Lamprell and Whitehead 1992: pl. 32 fig. 211.

Ctenocardia fornicata (G.B. Sowerby II, 1840) — ter Poorten 2009: pl. 10 figs 7–10; Huber 2010: 300, fig.; ter Poorten 2011: pl. 1101 figs 4–6.

Not: *Ctenocardia fornicata* (Sowerby, 1841) — Wilson and Stevenson 1977: 28–30, pl. 4 figs 10–13, text fig. 2.

MATERIAL EXAMINED

Australia: ***Western Australia:*** **Oceanic Shoals**, N. Scott Reef, N.E. corner, 13°59'S, 121°46'E (Egaz), 20 m, in rubble, 09.1996. Leg. H. Morrison, WAM Offshore Kimberley Survey 1996 (WAM S39930, 1 p.v.).

DESCRIPTION

Shell medium sized (L 20–39 mm), rather solid, well-inflated, inequilateral and quadrate, height approximately equals length. Umbonal keel strongly angled, anterior and ventral margin rounded, posterior margin straight or slightly concave. Between 37–44 squarish radial ribs with elaborate ornamentation on shell anterior, i.e. erect top spines or spinose scales and small bilateral spines; posteriorly likewise but often less well developed, occasionally ribs bearing only imbricated lamellae. Interstices narrow, finely striated. Lunule well delimited, similar sized in both valves. Exterior colour cream, mottled with brown-red, lunule purple; interior reflects exterior by translucency, white often suffused with yellow, orange or pink.

DISTRIBUTION AND ECOLOGY

The only WA record is from Scott Reef, part of the oceanic reefs of the outer shelf margin, where it was found sympatric with *C. gustavi*. In contrast, all other *Ctenocardia* samples of the continental coastal waters of northern WA proved to be *C. pilbaraensis* sp. nov., as were all Wilson and Stevenson (1977) records of *C. fornicata*. This species has a wide IWP distribution and has been live recorded from 15–80 metres depth (based on 24 samples).

REMARKS

The single recorded specimen has 41 ribs (range 37–44). Material under this name is reported by Lamprell and Whitehead (1991) from northern WA, but it is not clear which *Ctenocardia* species is involved: the given rib number (32–42) suggests a composite of *C. fornicata* and *C. pilbaraensis* sp. nov. records. The largest of the four possible syntypes of *C. fornicata* (NHMUK 1996513, H 26.7 mm) is figured for comparison (Figures 6M–O). Examination of the holotype of *Cardium adamsii* Reeve in A. Adams & Reeve, 1850 (NHMUK 1874.12.11.391) and comparison with the possible syntypes of *C. fornicata* has confirmed its synonymy.

Ctenocardia gustavi Vidal & Kirkendale, 2007

Figures 9A–D, 18B

Ctenocardia gustavi Vidal & Kirkendale, 2007: 98–100, figs 5e–g.

Ctenocardia gustavi Vidal & Kirkendale, 2007 — ter Poorten 2009: pl. 8 fig. 6, pl. 10 figs 4–6; Huber 2010: 300, fig.; ter Poorten 2011: pl. 1101 figs 1–3.

MATERIAL EXAMINED

Australia: ***Western Australia:*** **Oceanic Shoals**, Hibernia Reef, N. side, reef slope, immediately outside entrance to lagoon, 11°57.8'S, 123°22.3'E, 8–12 m, 10.05.1992. Leg. R.C. Willan (NTM P.13187, 1 s.v.); S.E. side, large pool in extensive reef flat, lagoon behind reef crest, 11°58.07'S, 123°22.08'E, 5 m, mixture of clean coral sand and *Halimeda*-algal sand, 12.05.1992. Leg. J.R. Hanley (NTM P.23197, 1 p.v., A); Ashmore Reef, lagoon, 12°13'50.34"S, 122°59'59.918"E, 12 m, 25.09.2013. Leg. L. Kirkendale & C. Bryce, Woodside Kimberley Survey 2013, Stn 122/K13 (WAM S75035, 1 p.v., A); N. Scott Reef, W. side lagoon 13°57'59"S, 121°52'24"E, 6–18 m, 11.09.1984. Leg. F. Wells & C. Bryce, WAM Scott / Seringapatam Reefs Survey 1984, Stn 8 (WAM S39929, 1 s.v.).

DESCRIPTION

Shell small to medium (L 15–25 mm), rather solid, well-inflated, inequilateral and quadrate. Umbonal keel strongly angled with concave posterior slope. Between 39–45 low flattened radial ribs carrying minute, densely placed and strongly arched lamellae of variable strength, becoming more pronounced near anterior and posterior

margins. Interstices narrow. Lunule present but small. Exterior cream with irregularly placed pale purple and yellowish spots. Small orange blotches on lunule and the most posterior rib(s). Interior variable, often white or with purple to orange umbonal ray on posterior quarter, sometimes with two reddish-brown rays.

DISTRIBUTION AND ECOLOGY

All WA samples of this species originate from the northern offshore reefs, indicating a strong biogeographic affinity with the IWP (Figure 18B). This is also true for the Kimberley record by Willan et al. (2015), from a project area that includes Hibernia Reef. The occurrence in WA is well established by the two live-collected specimens, found in 5–12 metres depth, which aligns with the presently known shallow water occurrence. The distribution covers the Central IWP.

Ctenocardia pilbaraensis sp. nov. ter Poorten & Kirkendale

Figures 8A–L, 18C, Table 2

urn:lsid:zoobank.org:act:655623C1-D53C-4D24-BEA4-0C19749C59B2

? *Trigoniocardia adamsi* (Adams & Reeve, 1850) — Habe and Kosuge 1970: 153, pl. 59 fig. 3.

Ctenocardia fornicata (Sowerby, 1841) — Wilson and Stevenson 1977: 28–30, pl. 4 figs 10–13, text fig. 2.

Ctenocardia fornicata (Sowerby, 1840) — Slack-Smith and Bryce 2004: 238; Taylor and Glover 2004: 263.

Ctenocardia fornicata (G.B. Sowerby, 1840) — Willan et al. 2015: 336 [*pars*].

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia:*** **Pilbara Nearshore/ Offshore**, near Onslow, W. side of Peak Island [21°36'5"S, 114°30'34"E], 10 fms (18 m), 18.06.1960, Western Australian Hawaiian Exped. (WAM S78025, ex 232–67, 1 p.v.).

Paratypes

Australia: ***Western Australia:*** **Pilbara Nearshore/ Offshore**, 38 nautical miles N. of Port Walcott, 19°59'S, 117°16'E to 20°01'S, 117°16'E, 50–52 m, 15.04.1982. Leg. L.M. Marsh, CSIRO FRV 'Soela' Cruise II 1982, Stn S02/82/54A (WAM S29235, 1 p.v., A, paratype); Dampier Archipelago, approx. 0.4 nautical miles W. of N.W. point of Goodwyn Island, 20°32.11'S, 116°31.55'E to 20°32.40'S, 116°31.22'E, 13–15 m, coarse shelly sand, 25.07.1999. Leg. J.D. Taylor & E.A. Glover, Woodside Dampier Exped. II 1999, Stn DA2/99/76 (WAM S22828, 1 p.v., A, paratype); Dampier Archipelago, 42–43 m. Woodside Dampier Exped. II, 07.1999 (MNHN-IM-2014-5525, 3 s.v., paratypes); off Onslow, dived, 20–25 m, c. 2010 (TP 4412, 1 p.v., paratype); near Onslow, W. side of Peak Island [21°36'5"S, 114°30'34"E], 10 fms (18 m), 18.06.1960, Western Australian Hawaiian Exped. WAM S67900, 4 p.v., 1 s.v., paratypes); Exmouth Gulf, off Exmouth Town Beach (Yacht Club), 34' (10 m), silty sand & shells, 15.08.1989. Leg. S.M. Slack-Smith & A. East (WAM S78108, 1 p.v., paratype).

Other materials

Malaysia: ***Sabah:*** N. point, channel between Banggi Island and mainland of Sabah [ca 7°N, 117°E], dived, 10.2006. Leg. H. Morrison (TP 3286, 1 p.v.).

Australia: ***Western Australia:*** **Canning**, Lacepede Archipelago, W. of Lacepede Island, 16°52'S, 122°09'E (Egaz), 48 m, 22.12.1969. Leg. K. Ozawa, Tokyo University of Fisheries Exped. FV 'Umataka Maru', 1969, Stn UMD6928 (WAM S57168, 2 s.v.); **North West Shelf**, Rowley Shoals, off Mermaid Reef, 17°46'6.23"S, 120°43'9.12"E to 17°45'56.87"S, 120°42'56.51"E, 97–109 m, 20.06.2007. Leg. C. Whisson & O. Gomez, CSIRO RV 'Southern Surveyor' Cruise, Stn SS0507/097 (WAM S32854, 1 s.v.); **Oceanic Shoals**, Imperieuse Reef, 17°36'S, 118°56'E (Egaz), 10.1974. Leg. E. Little (WAM S57002, ex 672-75, 1 s.v.); **Pilbara Nearshore/Offshore**, Dampier Archipelago, 2 miles W. of Legendre Island, 23 fms (42 m), sponge and rubble, 09.06.1960, Western Australian Hawaiian Exped. (WAM S78030, ex 235-67, 1 s.v., SEM coated specimen); N. of Nelson Rocks, 20°26.511'S, 116°40.256'E (Egaz), 6–24 m, 07.09.1999. Leg. S.M. Slack-Smith et al., Woodside Dampier Exped. III 1999, Stn DA3/99/67 (WAM S22444, 1 s.v.); 33 nautical miles N. of Rosemary Island, 19°55'S, 116°36'E, 58 m, shell & gravel, 29.09.1982. Leg. L.M. Marsh & M. Bezant on 'Soela', Stn S05/82/27A (WAM S78032, 2 s.v.); N. of Enderby Island, 19°50'S, 116°27'E to 19°52'S, 116°28'E, 65–70 m, 04.12.1979. Leg. S.M. Slack-Smith & L.M. Marsh on 'Soela', CSIRO # 001/0026&0027 (WAM S78031, 1 s.v.); Enderby Island, S.W. of Rocky Head, 20°37.111'S, 116°26.780'E (Egaz), 13–15 m, 06.09.1999. Leg. S.M. Slack-Smith et al., Woodside Dampier Exped. III 1999, Stn DA3/99/65 (WAM S22441, 1 s.v.); E.S.E. of Montebello Island, 20°39'S, 115°58'E to 20°39'S, 116°01'E, 27–29 m, 02.12.1979. Leg. S.M. Slack-Smith & L.M. Marsh on 'Soela', CSIRO # 001/0004-0005 (WAM S78028, 1 s.v.); E. side of Pasco Island, 20°58'S, 115°20'E, dredged, 1–2 fms (2–4 m), sand with some coral-heads, 02.09.1966. WAM-USNM Barrow Island, WA Exped. 1966, Stn 9 (WAM S78029, ex 258-67, 1 s.v.); Onslow, N. of Long Island, W. of Flat Island, 6–10 fms (11–18m), 19.06.1960, Western Australian Hawaiian Exped. (WAM S78024, 1 p.v., A); 7 miles N. of Long Island, 28 fms (51 m), fine sand and rubble, 17.06.1960, Western Australian Hawaiian Exped. (WAM S78129, 1 p.v., A); S. Muiron Island, off N.W. coast, 21°39.86'S, 114°20.06'E, 13–15 m, 25.08.1995. Leg. S.M. Slack-Smith et al., Stn 14 (WAM S78027, 1 s.v.); off W. coast,

FIGURE 9 A, B, C, D, *Ctenocardia gustavi* Vidal & Kirkendale, 2007. A–B, Ashmore Reef, WA: WAM S75035, length 17.0 mm. A, exterior of r.v., B, exterior of l.v.; C–D, Scott Reef, WA: WAM S39929, length 10.3 mm; C, exterior of r.v., D, interior of r.v.

E, F, G, H, I, J, K, L, *Microfragum festivum* (Deshayes, 1855). E–H, Clerke Reef, WA: WAM S40376, length 11.6 mm. E, exterior of l.v., F, exterior of r.v., G, interior of l.v., H, interior of r.v.; I–L, 'New Ireland' [Papua New Guinea, Bismarck Arch.]: NHMUK 1974134, syntypes. I–J, length 9.4 mm, I, exterior of l.v., J, interior of l.v., K–L, length 11.2 mm, K, exterior of l.v., L, interior of l.v.

M, N, O, P, Q, R, S, T, *Corculum cardissa* (Linnaeus, 1758). M–P, Cartier Reef, WA: NTM P.222. M–N, height 33.5 mm, M, interior of r.v., N, exterior of r.v., O, height 32.8 mm, exterior of l.v., P, height 31.2 mm, exterior of r.v.; Q–T, Clerke Reef, WA: WAM S39932. Q–R, height 22.0 mm, Q, exterior of l.v., R, interior of l.v. S–T, H 20.7 mm, S, exterior of r.v., T, interior of r.v.; U, Mermaid Reef, WA: WAM S39933, height 14.9 mm, exterior of r.v.

21°40.58'S, 114°19.12'E, 17–18 m, 20.08.1995. Leg. S.M. Slack-Smith et al., Stn 3 (WAM S78026, 1 s.v.); **Ningaloo**, Ningaloo Marine Park, Vlamingh Head, 21°46.903'S, 114°03.348'E to 21°46.806'S, 114°03.355'E, 38–39 m, 03.05.2007. Leg. M.P. Salotti, AIMS RV 'Cape Ferguson' Ningaloo Survey II, Stn CF4314/2007/D053 (WAM S78022, 1 s.v.); 21°48'15"S, 114°0'45"E to 21°48'14"S, 114°0'46"E (GPS), 45–50 m, rubble, sponges, etc., 12.02.2008. Leg. S.M. Slack-Smith, AIMS RV 'Solander' Cruise, Stn RVS4545-D144 (WAM S43495, 1 p.v.); S. of Vlaming Head, 08.1975. Leg. J. Hewitt (WAM S78023, 1 s.v.); off Osprey Sanctuary Zone, 22°18.263'S, 113°46.544'E to 22°18.505'S, 113°46.157'E, 55 m, coarse sand, 25.04.2006. Leg. M.P. Salotti, AIMS RV 'Cape Ferguson' Ningaloo Survey I, Stn CF4010&11/2006/D005 (WAM S78021, 1 s.v.); **Zuytdorp**, Shark Bay, N. of Dirk Hartog Island, 25°50'32.0"S, 113°03'24.0"E, 40 fms (73 m), on sand bottom, 15.05.1960. Ex coll. King, WAM Mariel King Hawaiian Exped., MV 'Davena' 1960 (WAM S78046, 1 s.v.).

Unknown provenance: (TP 2942, 1 p.v.).

DESCRIPTION

Shell medium sized (L up to 28.5 mm), solid, inequilateral, quadrate, inflated, height about equal to length (mean L/H ratio 1.02, n = 10, Table 2). Anterior and ventral margin rounded, postero-ventral corner angulate, posterior margin clearly to strongly concave. Umbonal keel strongly angled. Between 32 to 38 well developed radial ribs (mean rib number 35.2, n = 10, Table 2), anteriorly carrying projecting densely placed scales, of which the antero-dorsal ones are often broader than the ribs, gradually ventrally and posteriorly becoming more tubular spiny, slightly hollow ventrally. Rib sculpture easily wearing off, resulting in glossy ribs. Rib sides generally finely bi-sculptured with crowded, tiny ridges. Margins crenulated, rib impressions slightly extending into the shell. Interstices approximately half as wide as the ribs, ornamented with fine concentric striae. Lunule asymmetric: much larger in right valve, carrying between 10–12 finely sculptured riblets of irregular strength, in left valve smooth or indistinctly sculptured. Escutcheon poorly defined. Hinge plate nearly straight, hinge strong, right valve with two very unequal cardinal teeth, ventral one large and pointed, dorsal one small, teeth partly joint by dorsal saddle. Two right anterior and two right posterior laterals, approximately equidistant from cardinals, ventral ones much stronger. Left valve with two cardinals, one anterior and one posterior lateral tooth. Exterior white or cream with irregular brown or purple patches, lunule cream with one or two patches of deep purple; interior white or pale pink with pink to purple spot near posterior margin; hinge plate white except for purple spot below ligament and occasionally below lunule. Periostracum not observed.

REMARKS

Differs from *C. fornicata* by its smaller dimensions (L 20–28.5 mm), thicker shell, lower rib number (32–38 ribs, minute ribbing on lunule excluded), very crowded rib sculpture on the antero-dorsal slope, asymmetric lunule (much larger in right valve, Figure 8F), generally stronger concave posterior margin and much less colourful shell interior.

TABLE 2 Shell measurements of *Ctenocardia pilbaraensis* sp. nov. Width includes rib sculpture; not measured on worn material and loose valves.

Sample	Height (mm)	Length (mm)	Width (mm)	Ribs	L/H ratio
WAM S78025 (holotype)	19.0	19.8	15.7	36	1.04
WAM S67900 (paratype)	18.0	19.1	15.7	34	1.06
WAM S29235 (paratype)	10.0	10.1	7.9	34	1.01
WAM S43495	18.5	18.6	14.3	35	1.01
WAM S78021	21.7	21.5	–	37	0.99
WAM S78022	20.0	19.6	–	38	0.98
WAM S78031	25.3	24.3	–	37	0.96
WAM S78108 (paratype)	17.7	19.0	15.3	33	1.07
TP 4412 (paratype)	27.7	28.5	22.5	34	1.03
MNHN-IM-2014-5525 (paratype)	19.0	20.0	–	34	1.05
Mean values				35.2	1.02

DISTRIBUTION AND ECOLOGY

Sofar confined to northern WA. The presence of one Malaysian sample (Sabah, exact locality unknown, TP 3286, Figure 8L) suggests that it may not be an endemic WA species, however, additional material is needed for confirmation. Unlike *C. fornicata* and *C. gustavi*, this species is an inner continental or 'coastal' WA species with a depth range of 2–109 m (11–52 m alive) (Figure 18C). It is well established that there is a major separation between the molluscan faunas of the inner continental coast of WA and the offshore reefs (Willan 2005; Wilson 2013), and the fully allopatric distribution of *Ctenocardia pilbaraensis* sp. nov. compared to other WA *Ctenocardia* species offers additional corroboration for this idea. Habe and Kosuge (1970: pl. 59 fig. 3, as ?*Trigoniocardia adamsi*) depict a shell from unknown origin that looks very similar to the present species.

ETYMOLOGY

The specific epithet refers to the Pilbara, the area of the Australian North West Shelf where most of the type material has been found.

Genus *Fragum* Röding, 1798

Fragum Röding, 1798: 189. Type species by absolute tautonymy: *Fragum flavum* Röding, 1798 [= *Cardium fragum* Linnaeus, 1758]; Recent, 'O. Asiatico, Americano' (Indo-West Pacific; restricted to Ambon, Indonesia by Wilson and Stevenson 1977: 37).

Hemicardium Swainson, 1840: 373 (*non* Spengler, 1799; *nec* Schweigger, 1820). Type species by subsequent designation (J.E. Gray, 1847: 185): *Cardium unedo* Linnaeus, 1758; Recent (type locality not mentioned).

Fragum mundum (Reeve, 1845)

Figures 10A–L, 18D

Cardium mundum Reeve, 1845: sp. 125, pl. 22 fig. 125.

Cardium arcuatulum G.B. Sowerby III, 1874: 721, pl. 59 fig. 10.

Fragum thurstoni Dall, Bartsch & Rehder, 1938: 154–155, pl. 41 figs 9–10.

Fragum mundum (Reeve, 1845) — ter Poorten 2009: pl. 7 figs 3–4, Huber 2010: 298, fig.; pl. 8 fig. 3; ter Poorten 2011: pl. 1097 figs 2–3.

MATERIAL EXAMINED

Australia: ***Western Australia:*** **Oceanic Shoals**, Cartier Reef, N.E. end of cay, large shallow pool adjacent to reef flat, 12°31.7'E, 123°33.5'E, 2.5–6 m, on the undersurface of dead coral slabs, substrate of coarse coral sand with small pieces of unconsolidated coral rubble, 05.05.1992. Leg. R.C. Willan (NTM P.54210, 1 p.v., 1 s.v.); Ashmore Reef, Lower E. Side, 12°16'38.389"S, 123°08'09.935"E, 1 m, 28.09.2013. Leg. L. Kirkendale & C. Bryce, Woodside Kimberley Survey 2013, Stn 129/K13 (WAM S75212, 1 p.v.); Rowley Shoals, Clerke Reef, 17°23'15.758"S, 119°22'14.207"E, 0 m, 10.10.2014. Leg. C. Bryce, Woodside Kimberley Survey 2014, Stn 169/K14 (WAM S95498, 1 p.v., A); 17°09'35.169"S, 119°13'00.414"E, 0–3 m, 03.10.2014. Leg. C. Bryce, Woodside Kimberley Survey 2014, Stn Bedwell Is Shallow/K14 (WAM S95389, 1 s.v.); Imperieuse Reef, 17°30'32.938"S, 118°57'47.368"E, 15 m, 06.10.2014. Leg. C. Bryce, Woodside Kimberley Survey 2014, Stn 160/K14 (WAM S58124, 1 p.v., A); 17°30'20.627"S, 118°57'45.802"E, 0 m, 09.10.2014. Leg. C. Bryce, Woodside Kimberley Survey 2014, Stn 166/K14 (WAM S58115, 9 p.v., A; WAM S58116, 1 p.v., A; WAM S58117, 1 p.v., A; WAM S58118, 1 p.v., A; WAM S58119, 1 p.v., A; WAM S58120, 1 p.v., A; WAM S95383, 4 s.v.); **Pilbara Nearshore**, Dampier Archipelago, Kendrew Island, 20°28'30"S, 116°32'E, 3 m, 19.02.1973, Crown of Thorns Survey III Jan-Feb 1973, transect N1 (WAM S79509, 1 p.v.).

DESCRIPTION

Shell very small (H 5–12 mm), very inequilateral, rather solid, trapezoidal with rounded anterior margin and straight to slightly concave and serrate posterior margin. Posterior slope set off from the rest of the shell by a sharp radial angulation, forming a postero-ventral angle of approximately 65–80°. Between 26–30 radial ribs (of which 9–10 are on the posterior slope); ribs flat with more or less imbricate rather crowded scales on top, becoming spiny on the posterior slope. Interstices narrow, finely striated. Antero-dorsal margin not touching umbo, slightly depressed near it. Hinge plate broad, hook-shaped basement of the anterior lateral tooth. Exterior and interior cream to yellow (seldom with pinkish streaks posteriorly) with semi-translucent green-greyish or tan spots, of the same width as the ribs, acting as shell windows; windows associated with well-defined interior convexities in the umbonal keel region.

Distribution and ecology — In Australia, *F. mundum* is known from QLD based on Shirley (1912) who reports '*Cardium munda* Reeve' from Bundaberg (material not traced) and samples from Heron Island (MNHN-IM-2014-5528, leg. J. Vidal, det. TP) and Lizard Island (UF 375687, leg. L. Kirkendale). The distribution of this species, which now includes northern WA (Figure 18D), encompasses the full IWP. Reeve's (1845) type locality, 'Lord Hood's Island, Pacific Ocean (found among coral sand)' is to be interpreted as Tuamotu Archipelago, South Marutea, 21°30'S, 135°33'W (Dance 1986: 112; Higo et al. 1999: 471), a south central Pacific penetration. Together with Hawaii in the northern Pacific (UF 296894) and other sites in the Western Pacific (e.g. Guam UF 288909, Tuvalu UF347854) this

is a widespread distribution in the Pacific. However, the addition of recent records from S. Madagascar (MNHN, ATIMO VATAE Exped., det. TP), together with WA records, including Christmas Island (UF 337833), implies one of the largest ranges of all living Cardiidae. *Fragum mundum* is a shallow water species; available data suggest a partly epifaunal live habit, associated with corals and rocks, exposed, or to some extent nestling in crevices via a byssal attachment. It is a member of the photosymbiotic fragines and like *C. cardissa*, has transparent shell microstructural windows that facilitate light penetration through the shell (Persselin 1998; Kirkendale 2009).

REMARKS

The WA records are morphologically quite heterogeneous, with a different rib sculpture and a variable postero-ventral angle, possibly resulting from the epifaunal nestling lifestyle. Part of the type material (NHMUK 1978138, three syntypes, Figures 10I–J) is figured for comparison and specimens were chosen to highlight this heterogeneity. This observation, together with an enormous geographic range, indicates that this small species (H up to 12 mm) may represent a species complex. *Fragum mundum* has been mistaken for juvenile *Fragum fragum* (Linnaeus, 1758) and this could in part explain the recent recognition of this species in WA (Willan et al. 2015).

Fragum sp. aff. *scruposum* (Deshayes, 1855)

Figures 10M–O

Cardium scruposum Deshayes, 1855: 333.

Hemicardium (*Fragum*) *fragum* var. *carinata* Lynge, 1909: 261, pl. 5 fig. 20 (not preoccupied by *Cardium carinatum* Bronn, 1831 nor *Cardium carinatum* Deshayes, 1838).

Corculum (*Fragum*) *bannoi* Otuka, 1937: 138–139, figs 54a–b.

Fragum bannoi Y. Otuka, 1937 — Huber 2010: 297, fig.

Fragum (*Fragum*) *carinatum* (Lynge, 1909) — Kendrick 1990: 37, fig. 2.

Not: *Fragum scruposum* (Deshayes, 1855) — ter Poorten 2009: pl. 7 figs 5–8, pl. 8 fig. 2; Huber 2010: 298, fig.; ter Poorten 2011: pl. 1097 figs 6–7 (= *F. whitleyi*).

MATERIAL EXAMINED

Australia: *Western Australia:* Houtman Abrolhos Islands, W. Wallaby Island, W. Beach. Leg. E.P. Hodgkin, 06.02.1964 (WAM S78123, 1 s.v.).

DESCRIPTION

Shell small (H 10–19 mm), inequilateral, solid, moderately inflated, subquadrate, with pronounced medio-posterior angulation, a postero-ventral angle of approximately 75–80° and with a rounded anterior margin. Antero-ventral margins crenulate, posterior margin deeply serrate. Between 20–23 strong low-rounded radial ribs (of which 8–10 on posterior slope), posteriorly smaller and more pointed triangular, umbonal keel prominent, formed by 1–2 strongly thickened ribs. Anterior and median ribs regularly covered with tubercles or coarse scales, finely tubercular posteriorly; interstices rather broad. Exterior and interior white.

DISTRIBUTION AND ECOLOGY

Fragum scruposum is currently known from Thailand, Malaysia, China, Taiwan, Indonesia, Solomon Islands, New Caledonia, Vanuatu and Fiji (colln MNHN, NTM, TP, J. Hylleberg, det. TP), hence the record from WA suggests a biogeographic affinity with the IWP.

REMARKS

The record of *F. scruposum* in WA is uncertain, firstly, because of the doubtful Recent nature of the sample and secondly, because the taxonomy of this, and related species, is complicated. WAM S78123 (Figures 10M–N) is a worn left valve with 22 ribs, including one thickened rib that could not be identified to species level with certainty; the height (19.2 mm) is greater than usual for *F. scruposum*. Its origin (Houtman Abrolhos Islands) may reflect a tropical penetration, as these islands are located in the path of the warm southerly flowing Leeuwin Current. Given the worn state, it cannot be unequivocally considered Recent and its presence in the modern Australian fauna needs to be confirmed by additional finds. Kendrick (1990, as *Fragum* (*Fragum*) *carinatum*) reports very similar material from Late Pleistocene deposits of Shark Bay and McNamara and Kendrick (1994) discuss additional finds from the Late Pleistocene of Barrow Island. Their material (WAM 87.594, Figure 10O) is in agreement with *F. scruposum*. Its presence in the Middle and Late Pleistocene assemblages is well established and it has been reported from the younger Quaternary of the Carnarvon and Perth Basins (McNamara and Kendrick 1994).

The three syntypes of the present species (NHMUK 1974140, Hylleberg 2004: 907, unnumbered figs; ter Poorten 2015: fig. 8a–b) have 1–2 pronounced ribs in both valves, coinciding with a strong carina running from the umbo to the postero-ventral corner. The total rib number is 21, 22 and 23 (counted on l.v.). The same rib structure and number counts for the type figure of *Hemicardium* (*Fragum*) *fragum* var. *carinata* Lynge, 1909 (pl. 5 fig. 20) and for Otuka's (1937: figs 54a–b) type figures of *Corculum* (*Fragum*) *bannoi* (Otuka, 1937). Examination of various samples of *F. scruposum* makes clear that the carina of a given specimen is predominantly composed of one thickened rib on the

FIGURE 10 A, B, C, D, E, F, G, H, I, J, K, L, *Fragum mundum* (Reeve, 1845). A–D, Ashmore Reef, WA: WAM S75212, height 7.6 mm. A, exterior of r.v., B, exterior of l.v., C, interior of l.v., D, interior of r.v.; E–H, Dampier Arch., WA: WAM S79509, height 9.3 mm. E, exterior of r.v., F, exterior of l.v., G, interior of r.v., H, interior of l.v.; I–J, Lord Hood's Island: NHMUK 1978138, syntypes. I, height 8.8 mm, exterior of l.v., marked '63', J, height 8.8 mm, exterior of l.v.; K–L, Cartier Reef, WA: NTM P.54210, height 8.3 mm. K, exterior of l.v., L, interior of l.v.

M, N, O, *Fragum* sp. aff. *scruposum* (Deshayes, 1855). M–N, Houtman Abrolhos Islands, WA: WAM S78123, height 19.2 mm. M, exterior of l.v., N, interior of l.v.; O, Shark Bay, WA (Pleistocene): WAM 87.594, height 13.2 mm, exterior of l.v.;

P, Q, R, S, *Fragum whitleyi* Iredale, 1929; P–Q, Ashmore Reef, WA: WAM S91688, height 6.2 mm. P, exterior of l.v., Q, interior of l.v.; R–S, Ashmore Reef, WA: WAM S91571, height 10.5 mm. R, exterior of l.v., S, exterior of r.v.

T, U, V, W, *Fragum sueziense* (Issel, 1869). Montebello Islands, WA: WAM S78323. T–U, length 5.9 mm, T, exterior of l.v., U, interior of l.v., V–W, length 5.1 mm, V, exterior of l.v., W, interior of l.v.

left valve, marginally interlocking with two thickened ribs on the right valve (e.g. TP 4064). Because of the similar shell morphology, *Hemicardium* (*Fragum*) *fragum carinata* Lynge, 1909 and *Corculum* (*Fragum*) *bannoi* (Otuka, 1937) are considered junior synonyms of *Fragum scruposum*. Taxonomic revision of the genus and molecular analysis is needed for a full systematic resolution that is outside the scope of this paper. Fischer-Piette (1977) considered *Hemicardium* (*Fragum*) *fragum carinata* Lynge, 1909 a junior homonym of *Cardium carinatum* Bronn, 1831: this opinion cannot hold as both taxa are not originally nor subsequently combined with the same generic name (ICZN 1999: Art. 53.3).

Fragum sueziense (Issel, 1869)

Figures 10T–W, 18E

Cardium sueziensis Issel, 1869: 76, 252, pl. 3 fig. 4

? *Cardium* (*Acanthocardia*) *omanense* Melvill in Melvill & Standen, 1907: 838–839, pl. 53 fig. 5

Cardium transclathratum Viader, 1951: 143, pl. 3 fig. 7.

Fragum sueziense (Issel, 1869) — ter Poorten 2009: pl. 7 figs 9–11, pl. 8 fig. 4; Huber 2010: 298, fig.; ter Poorten 2011: pl. 1097 figs 4–5.

MATERIAL EXAMINED

Australia: ***Western Australia:*** **Canning**, N. of Broome, 17°58'S, 122°14'E, 56 m, 21.12.1969. Leg. K. Ozawa, Tokyo University of Fisheries Exped. FV 'Umataka Maru' 1969, Stn UMD6925 (WAM S57164, 1 s.v.); **Oceanic Shoals**, Clerke Reef, 17°17'51.826"S, 119°21'32.899"E, 15 m, 04.10.2014. Leg. C. Bryce, Woodside Kimberley Survey 2014, Stn 155/K14 (WAM S68163, 1 p.v., A); **Pilbara Nearshore/Offshore**, off Port Hedland, 20°19'S, 118°37'E, 09.10.1982. Leg. L.M. Marsh & M. Bezant, CSIRO FRV 'Soela' Cruise V 1982, Stn (WAM S78308, 1 s.v.); Dampier Archipelago, Cape Lambert, 20°35'33.0"S, 117°11'01.0"E, 02.1981. Leg. T. Meagher et al. (WAM S84245, 1 p.v., A); 20°23'S, 116°52'E (WAM S78321, 1 s.v.); near the southern shore of Boat Passage, 20°31.4'S, 116°49.9'E, 08.1978. Leg. S.M. Slack-Smith, Stn ML11/6 (WAM S78309, 2 s.v.); inside Withnell Bay, 20°34'43.0"S, 116°47'14.0"E, 12.1980. Leg. T. Meagher et al. (WAM S84497, 3 p.v., A); Rosemary Island, 20°29'S, 116°36'E, beach strand line, 21.05.1972. Leg. B.R. Wilson, Crown of Thorns Survey I May 1972 (WAM S78302, 1 s.v.); Montebello Islands, S. of Gannet Islands, to E. of Delta Island, 20°27'00"S, 115°33'59"E, 4–6 m, 14.08.1993. Leg. S.M. Slack-Smith, WAM Montebellos Islands Survey 1993, Stn MB12 (WAM S78293, 1 s.v.); E. side of Hermite Island, 20°28'35"S, 115°33'03"E, 4 m, coarse sand, 24.08.1993. Leg. S.M. Slack-Smith, WAM Montebellos Islands Survey 1993, Stn MB36a (WAM S78323, 2 s.v.); Bunsen Channel, N. end of Trimouille Island, 20°23'08"S, 115°32'43"E, 3 m, 21.08.1993. Leg. C. Bryce & S.M. Slack-Smith, WAM Montebellos Islands Survey 1993, Stn MB28a (WAM S78109, 1 s.v.); E. side of Hermite Island, sandy beach, rock platform below oyster cliffs, 20°28'29"S, 115°32'43"E, 24.08.1993. Leg. L.M. Marsh, WAM Montebellos Islands Survey 1993, Stn MB36b (WAM S78310, 1 s.v.); Stephenson Channel near S. end of Hermite Island, 20°28'21"S, 115°32'27"E, 4 m, 15.08.1993. Leg. S.M. Slack-Smith, WAM Montebellos Islands Survey 1993, Stn MB15a (WAM S78305, 1 s.v.; WAM S78306, 2 s.v.); sandbank connecting Hermite & Buttercup Islands, intertidal sandflats, 20°29'S, 115°32'E, 15.08.1993. Leg. S.M. Slack-Smith, WAM Montebellos Islands Survey 1993, Stn MB14c (WAM S78318, 2 s.v.); Hermite Island, Sherry Lagoon, 20°29'20"S, 115°31'50"E, intertidal embayment, muddy sand & deeper channel, I/s cliffs, 16.08.1993. Leg. S.M. Slack-Smith, WAM Montebellos Islands Survey 1993, Stn MB14e (WAM S78328, 1 s.v.); sand bank near anchorage of CALM base, Hermite Island, 20°29'02"S, 115°31'46"E, intertidal sandbank, 14.08.1993. Leg. S.M. Slack-Smith, WAM Montebellos Islands Survey 1993, Stn MB14a (WAM S78249, 1 s.v.); Exmouth Gulf, 14 km E. of Muiron Island, Hawksbill Exploration Field, 21°41'S, 114°31'E, 15 m, 17.01.1994. Apache Energy Exmouth Gulf Survey 1993–94 (WAM S15923, 1 s.v.); N. end of Mydas Oil Rig, 21°45'S, 114°23'E, 11.11.1993. Leg. Hadson Energy (WAM S78291, 1 s.v.); Midas Exploration Field, 4 km S. of Muiron Islands, 21°45'S, 114°22'E, 15 m, 20.11.1993. Leg. Apache Energy (WAM S84481, 1 p.v., A, 2 s.v.); North West Cape, Bay of Rest, 22°19'S, 114°08'E, 09.1987. Leg. F.E. Wells & C.W. Bryce (WAM S84248, 1 p.v., A); **Ningaloo**, Ningaloo Reef, off N. point of Mangrove Bay, transect 6, 22°17'S, 113°48'E, 1980. Leg. T.D. Meagher & Assoc. (WAM S78163, 1 p.v.); N. of Pt. Cloates, N. end of Bay, 22°37'S, 113°38.5'E, bottom of sand, sponge & dead shells, 30.08.1968. WAM Ningaloo Exped. 1968 (WAM S84251, 2 p.v., A); Maud's Landing, N. of Carnarvon, 23°07'S, 113°46'E, 07.1971. Leg. D. & B. Parker (WAM S78313, 1 s.v.); Coral Bay, 23°09'S, 113°46'E, beach collection, 04.06.1981. Leg. C. Bryce & S.M. Slack-Smith (WAM S78340, 1 s.v.); **Houtman Abrolhos Islands**, Easter Group, N.E. of Rat Island, E. of Shag Rock, 28°42'S, 113°46.5'E, grab, 23.08.1977. Leg. C.W. Bryce & L. Baxter, FRV 'Flinders' Dredging Cruise 1977, Stn G9 (WAM S84480, 1 p.v., A).

DESCRIPTION

Shell very small (H 5–10 mm), rather solid, moderately inflated, subquadrate or rounded, generally slightly inequilateral with posterior margin somewhat straightened, but at times equilateral. Margins crenulate. Umbonal keel barely developed. Between 22–28 rather low and broad square radial ribs, topped with tubercles or slightly curved scales, sometimes partly commarginally aligned. Interstices often with concentric striae, varying from close set to quite widely spaced. Antero-dorsal margin not touching umbo, with most antero-dorsal part of the shell depressed beside umbo.

Coloration completely white to cream occasionally with brown-pink spots or 2 purple-brown rays, visible inside and outside, or rarely completely lemon yellow.

DISTRIBUTION AND ECOLOGY

The present samples appear to represent the first Australian published records. In WA it has been recorded from shallow water (depth range 3–15 metres, one additional 56 metres record probably due to downslope transportation), mostly from onshore environments and one oceanic record (Figure 18E). Published data from QLD are lacking, however, several samples from Lizard Island are known: NTM P.54217 (leg. R.C. Willan, 07.10.1982, det. TP), UF 375842, UF 380191 (both leg. L. Kirkendale, 18.07.2003) and MNHN-IM-2014-5526 (leg. J. Vidal, 17.10.1994, det. TP), the latter consisting of no less than 40 valves. It has a wide IWP distribution.

REMARKS

Although this small-bodied species has likely been overlooked in many surveys that focus on macromolluscs, it not only proved to be one of the dominant bivalve taxa in the quantitative bulk samples of the northern bay of Safaga, Red Sea (Zuschin and Oliver 2003), but was also the most abundant cardiid species of the Philippine Panglao Marine Biology Project (both in terms of numbers of specimens and samples) (ter Poorten 2009). It is photosymbiotic and and can often be found in quite deep water compared to other photosymbiotic cardiids (e.g. 32–36 m live collected in Atoll Surprise, N. New Caledonia, MNHN, Stn DW1381; ter Poorten 2015: table 1) and is often found beached in shell grit. A few additional southerly WA samples are excluded as the locality is either questionable or the material does not have a recent appearance.

Fragum whitleyi Iredale, 1929

Figures 10P–S, 18F

Fragum whitleyi Iredale, 1929: 264, pl. 30 fig. 14.

Fragum (*Fragum*) *scruposum* (Deshayes, 1855) — Lamprell and Whitehead 1992: pl. 31 fig. 206.

Fragum scruposum (Deshayes, 1855) — ter Poorten 2009: pl. 7 figs 5–8, pl. 8 fig. 2; Huber 2010: 298, fig.; ter Poorten 2011: pl. 1097 figs 6–7.

MATERIAL EXAMINED

Australia: ***Northern Territory:*** **Pellew**, W. coast of Gulf of Carpentaria, Borroloola, 1 km downstream from mouth of Bing Bong Creek, 15°48'S, 136°37'E, 2–3 m, 06.09.1992. Leg. R.C. Willan (NTM P.1936, 1 p.v., A); **Groote**, N.W. coast of Gulf of Carpentaria, beach immediately adjacent to Port Bradshaw, 12°32.75'S, 136°44.35'E, 06.07.1994. Leg. K. Colgan (NTM P.4357, 2 s.v.); **Arnhem Wessel**, N.W. coast of Gulf of Carpentaria, Melville Bay, western side of Gove Peninsula, 12°15'S, 136°43'E, 12–17 m, 07.1991. Leg. J.R. Hanley & party (NTM P.37511, several s.v.).

Australia: ***Western Australia:*** **Oceanic Shoals**, Ashmore Reef, Lower E. side, 12°16'38.389"S, 123°08'09.935"E, 1 m, 28.09.2013. Leg. L. Kirkendale & C. Bryce, Woodside Kimberley Survey 2013, Stn 129/K13 (WAM S91688, 1 s.v.); East Island, 12°16'S, 123°06'E, beach collection, 02.10.1977. Leg. J. Griffith, WAM Ashmore Reef and Cartier Island Survey 1997 (WAM S57144, 6 s.v.; WAM S84271, 1 s.v.); S. end, 12°15'44.388"S, 122°59'05.425"E, 1 m, 02.10.2013. Leg. L. Kirkendale & C. Bryce, Woodside Kimberley Survey 2013, Stn 137/K13 (WAM S91571, 1 p.v., A); **Pilbara Nearshore**, Dampier Archipelago, Rosemary Island, Norbil Bay, 20°29'S, 116°35'E, 1–2 m, dredge, 21.05.1972. Leg. B.R. Wilson, Crown of Thorns Survey 1 (WAM S13359, > 20 p.v., A); **Houtman Abrolhos Islands**, Easter Group, N.E. of Rat Island, 28°42'S, 113°46'5"E, grab, 23.07.1977. Leg. C. Bryce & L. Baxter, FRV 'Flinders' Dredging Cruise, Stn G12 (WAM S13366, 1 p.v., A).

DESCRIPTION

Shell small (H 10–17 mm), solid, inequilateral, moderately inflated, subquadrate, a postero-ventral angle of approximately 80–90° and with a rounded anterior margin. Antero-ventral margins crenulate, posterior margin serrate. Posterior slope set off from the rest of the shell by a clear radial angulation. Between 25–29 squarish to low-rounded radial ribs, posteriorly smaller, umbonal keel formed by 1–2 ribs that can be slightly thickened. Anterior ribs regularly covered with tubercles, median ribs with coarse, close-set scales, posterior ribs finely tubercular. Interstices rather broad and finely striate. Exterior white, occasionally lemon yellow or pinkish; interior white, rarely with a yellowish umbonal cavity.

DISTRIBUTION AND ECOLOGY

This species is described from QLD, Michaelmas Cay (Great Barrier Reef). In WA and NT it is known from several onshore and offshore records with the Houtman Abrolhos Islands as the southernmost record (Figure 18F). It has a wide distribution in the IWP, living in shallow waters.

REMARKS

Part of the studied material is tentatively assigned to the present species, with a shell morphology and rib number that correspond to *Fragum whitleyi* rather than to *F. scruposum*. On the other hand, the ribbing pattern is rather heterogenous (Figures 10P–S) and the species boundaries are not resolved. Like other small to medium sized *Fragum* species, the species is in need of a full taxonomic revision.

Genus *Microfragum* Habe, 1951

Microfragum Habe, 1951: 148. Type species by original designation: *Cardium festivum* Deshayes, 1855; Recent, 'New Ireland' (Bismarck archipelago, Papua New Guinea).

Microfragum festivum (Deshayes, 1855)

Figures 9E–L, 18G

Cardium parvum G.B. Sowerby II, 1839: fig. 33; 1840b: 6, sp. 80; 1841: 110 (*non* Da Costa, 1778; *nec* Philippi, 1844).

Cardium festivum Deshayes, 1855: 332.

Ctenocardia (*Microfragum*) *festiva* (G.P. Deshayes, 1855) — Huber 2010: 300, fig.

Microfragum festivum (Deshayes, 1855) — Lamprell and Whitehead 1992: pl. 32 fig. 213; ter Poorten 2009: pl. 9 figs 6–7; ter Poorten 2011: pl. 1104 figs 2–4.

MATERIAL EXAMINED

Australia: ***Western Australia:*** **Oceanic Shoals**, Ashmore Reef, approx. mid-northern coast, 12°13.47'S, 122°57.77'E, on the surface of silty sand, at the base of outer reef slope, 22 m, 10.09.1996. Leg. R.C. Willan (NTM P.24387, 1 s.v.); Rowley Shoals, Clerke Reef, 17°16'26"S, 119°21'34"E, intertidal sand flat, 0 m, 22.07.1982. Leg. WA Museum Party, WAM Rowley Shoals Exped. 1982, Stn 16 (WAM S40376, 1 p.v., A); 17°20'S, 119°20'E, coral clean sand substrate, 0–1 m, 21.08.1983. Leg. B.C. Russell (NTM, P.40065, 1 s.v.).

Literature records: Willan (2005: 79): Ashmore Reef; Wilson (2013: 353): Oceanic Shoals.

DESCRIPTION

Shell small to medium (L 10–15 mm), solid, subequilateral, rounded quadrate, longer than high and with a rather weak medio-posterior radial angulation. Margins rounded, posterior margin slightly truncated. Between 33–45 radial ribs. Ribs flattened, rounded and densely covered with arched, thin imbricated lamellae that easily wear off, even in fresh material. The lamellae are of a homogeneous size and strength. Interstices narrow and finely punctuated. Exterior colour whitish to cream with brown-pinkish splashes; interior variable, ranging from white to orange in umbonal cavity or with brownish rays.

DISTRIBUTION AND ECOLOGY

All WA records are found intertidally or in shallow water off the oceanic northern offshore reefs (Figure 18G; see also Wilson 2013: table 8.8). It is a widespread tropical Central IWP species, also known from QLD (Lamprell and Whitehead 1992; live collected by the second author at Lizard Island, UF 374119) and East Timor (ZMA, Siboga Exped., Stn 282, 1 p.v., det. TP). It predominantly occurs in lagoons and other non-exposed shallow water environments, occupying soft bottoms and coral sand (ter Poorten 2009).

REMARKS

Two of the syntypes are figured for comparison (NHMUK 1974134, Figures 9I–L). The scales easily wear off, rendering specific separation with the partly sympatric *M. subfestivum* (Vidal & Kirkendale, 2007) sometimes problematic, although the latter has broader interstices. WA samples of this latter species were not present in the WAM and NTM collections, but this species is also likely to occur in northern Australia given its occurrence in South Indonesia.

Subfamily Cardiinae Lamarck, 1809

REMARKS

Following the molecular phylogenetic study of Herrera et al. (2015), *Fulvia* and *'Laevicardium' lobulatum* are placed in Cardiinae. Clade 6 of this study includes three subclades, the first containing *'L.' lobulatum*; the second *Europicardium*, *Cardium* and *Bucardium* and the third *Fulvia*. Following ter Poorten and Hylleberg (2017), *Laevifulvia* is synonymised with *Fulvia*.

Genus *Fulvia* J.E. Gray, 1853

Fulvia J.E. Gray, 1853: 40. Type species by monotypy: *Cardium apertum* Bruguière, 1789; Recent, 'l'océan Asiatique' & 'Jamaïque' (Indo-West Pacific; Jamaica in the original publication was in error).

Laevifulvia Vidal, 1994: 97 (as a subgenus of *Fulvia*). Type species by original designation: *Cardium hungerfordi undatopictum* Pilsbry, 1904; Recent, 'Hirado, Hizen' [Kyūshū, Nagasaki Pref.], Japan.

Fulvia australis (G.B. Sowerby II, 1834)

Figures 11A–D, 19C

Cardium striatum Spengler, 1799: 45 [never used].

Cardium australe G.B. Sowerby II, 1834: figs 12, 12*.

Cardium varium G.B. Sowerby II, 1834: fig. 19.

Cardium pulchrum Reeve, 1845: sp. 98, pl. 19 fig. 98.

Fulvia australe (Sowerby, 1834) — Lamprell and Whitehead 1992: pl. 34 fig. 227.

Fulvia (*Fulvia*) *australis* (G.B. Sowerby II, 1834) — ter Poorten 2009: pl. 12 figs 6–10; Huber 2010: 304, fig. (*pars*); ter Poorten 2011: pl. 1108 figs 1–2.

FIGURE 11 A, B, C, D, *Fulvia australis* (G.B. Sowerby II, 1834). A–B, Seringapatam Reef, WA: WAM S39958, length 22.6 mm. A, exterior of r.v., B, interior of r.v.; C–D, De Freycinet Island, WA: WAM S66931, length 24.1 mm. C, exterior of l.v., D, interior of l.v.

E, F, *Fulvia laevigata* (Linnaeus, 1758). Coronation Island, WA: WAM S56804, length 31.5 mm. E, exterior of l.v., F, interior of l.v.

G, H, I, J, *Fulvia boholensis* Vidal, 1994. Dampier Arch., WA: NTM P.54198, length 24.2 mm. G, exterior of r.v., H, exterior of l.v., I, interior of r.v., J, interior of l.v.

K, L, *Fulvia fragiformis* Vidal, 1994. Great Barrier Reef, QLD: NTM P.19858, length 17.0 mm. K, exterior of l.v., L, interior of l.v.

M, N, O, *Fulvia hungerfordi* (G.B. Sowerby III, 1901). M, N. of Newcastle, NSW: NTM P.36678. length 4.7 mm (defect), exterior of r.v.; N–O, Darwin, NT: NTM P.7260, length 5.0 mm (defect). N, exterior of r.v., O, interior of r.v.

P, Q, R, S, T, *Fulvia scalata* Vidal, 1994. P–S, off Mermaid Reef, WA: WAM S34673. P–Q, height 14.7 mm, P, exterior of r.v., Q, interior of r.v., R–S, height 16.4 mm, R, exterior of r.v., S, interior of r.v.; T, Tiwaka River mouth, New Caledonia: MNHN-IM-2000-4021, holotype, length 19.3 mm, exterior of r.v.

U, V, W, X, Y, *Fulvia undatopicta* (Pilsbry, 1904). U, N. of Port Walcott, WA: WAM S78297, height c. 6.5 mm (broken), exterior of l.v.; V–Y, E. of Muiron Islands, WA: WAM S78338, height 4.8 mm. V, exterior of r.v., W, exterior of l.v., X, interior of r.v., Y, interior of l.v.

MATERIAL EXAMINED

Australia: ***Northern Territory:*** **Cobourg**, Port Essington, 5 nautical miles N.W. of Smith Point, western end of Orontes Reef, 11°4'S, 132°3'E, 17 m, 09.08.1986. Leg. R.C. Willan (NTM P.54200, 1 p.v.).

Australia: ***Western Australia:*** Kimberley, Malcolm Island, 14°31'S, 125°54'E, 31.10.1976. Leg. S.M. Slack-Smith, WAM Admiralty Gulf Mangal Survey 1976 (WAM S66929, 2 p.v., 1 s.v.); De Freycinet Island, 14°59.03'S, 124°32.03'E, diving, 32 m, 01.12.1996. Leg. C. Bryce, WAM Central Kimberley Coast Survey 1996 (WAM S66931, 1 s.v.); **Canning**, Packer Island, 16.56675°S, 122.72845°E, benthic dredge, 15.8–16.6 m, 25.06.2008. Leg. J. Keesing, CSIRO Survey June 2008, Stn 487 (WAM S44417, 2 p.v., A); **Oceanic Shoals**, Seringapatam Reef, Lagoon, 13°38'S, 122°05'E, 16.09.1994. Leg. C. Bryce & H. Morrison, Bryce & Morrison Kimberley Survey 1994 (WAM S39958, 1 s.v.); Lagoon, 13°38'S, 122°05'E, 8 m, 16.09.1996. Leg. C. Bryce & H. Morrison, WAM Offshore Kimberley Survey 1996 (WAM S39916, 1 s.v.); Scott Reef, S. end, 14°11'55"S, 121°47'35"E, intertidal sand flat, 0 m, 15.09.1984. Leg. F. Wells & C. Bryce, WAM Scott & Seringapatam Reefs Survey 1984, Stn 19 (WAM S40377, 2 p.v., A); **Pilbara Nearshore**, Dampier Archipelago, Lady Nora Flats, N.E. side of Rosemary Island, 20°29'S, 116°36'E, 30.10.1971. Leg. B.R. Wilson (WAM S66930, 2 p.v., 1 s.v.); Rosemary Island, Norbill Bay, 20°29'S, 116°35'E, dredge, sand, 1–2 m, 21.05.1972. Crown of Thorns Survey 1 (WAM S82972, 4 p.v., A); Mermaid Passage, 20°42.42'S, 116°30.31'E, comminuted rubble incorporating some silt, 10 m, 21.08.1994. Leg. R.C. Willan (NTM P.21678, 1 p.v., 1 s.v.); N. of N.W. point of Eaglehawk Island, 20°38.94'S, 116°26.22'E, sponges, soft corals, gorgonians, 10 m, 03.09.1999. Leg. S.M. Slack-Smith et al., Woodside Dampier Exped. III 1999, Stn DA3/99/56 (WAM S22190, 1p.v., A); **Zuytdorp**, S. of Ningaloo Marine Park, 24°00.9114'S, 113°26.4864'E, epibenthic sled, 27.6–27.7 m, 03.02.2008. Leg. M.P. Salotti & S.M. Slack-Smith, AIMS-WAM RV 'Solander', Stn RVS4545/2008/D080 (WAM S84236, 1 p.v., A).

Literature records: Willan (2005): Hibernia Reef; Wilson (2013: 353): Oceanic Shoals, Pilbara and Canning.

DESCRIPTION

Shell medium sized (H 25–35 mm), rather thin, slightly obliquely ovate, H/L ratio highly variable, normally height approximately equals length. Between 34–55 radial ribs, well developed and irregular on posterior third of the shell and nearly smooth on median part. Periostracal insertions present on posterior part of the ribs. Minute, evenly disposed granulations often observed on anterior half of the shell. Lunular heart small, raised and elongate, equally sized in both valves. Colour variable, often whitish blotched with pink, purple or brown. Interior white, yellowish, orange or purple; sometimes with a purple umbonal ray.

DISTRIBUTION AND ECOLOGY

This study and Willan et al. (2015) provides records from coastal and offshore areas of northern WA and coastal NT (Figure 19C). It is also known from QLD (WAM, RMNH, TP) and is a common and widespread IWP species. The species lives intertidally and in shallow waters (depth range life taken WA samples: 0–28 meters) on mud and sand, often in association with seagrass.

REMARKS

Due to a resemblance with other congeners and the paucity of diagnostic characters, it may well have been overlooked. A rather similar looking species, *Fulvia nienkeae* ter Poorten, 2012, is known from QLD, based on records in RMNH (ex ZMA), NTM and NHMUK (det. TP). It can be distinguished from *F. australis* by its slightly larger size (up to 44 mm), higher rib number (54–68), more quadrangular-elongate shape (H > L), and large lunular area. Additionally, it lives in somewhat deeper water than *F. australis*. Another closely related but poorly known species, *Fulvia fragiformis* Vidal, 1994, is reported from Australia for the first time (Myrmidon Reef, QLD, NTM P.19858) and is figured for comparison (Figures 11K–L). It has a characteristic, strongly inequilateral fragiform shape.

Fulvia boholensis Vidal, 1994

Figures 11G–J

Fulvia (*Fulvia*) *boholensis* Vidal, 1994: 107, pl. 3 figs 6a–b; ter Poorten 2009: pl. 13 figs 1–4; Huber 2010: 304, fig.; ter Poorten 2011: pl. 1107 figs 3–5.

MATERIAL EXAMINED

Australia: ***Western Australia:*** **Pilbara Nearshore**, Dampier Archipelago, Mermaid Passage, 20°42.42'S, 116°30.31'E, fine rubble incorporating some silt, 10 m, 21.08.1994. Leg. R.C. Willan (NTM P.54198, 1 p.v.)

Literature records: Vidal (1994): Dampier (QM, 1).

DESCRIPTION

Shell medium sized (L 30–37 mm), rather thin, obliquely ovate, usually longer than high, quite often very slightly gaping posteriorly. Between 47–55 flattened but readily visible radial ribs, more pronounced on posterior third of the shell. Internal marginal ribbing relatively smooth. Periostracal insertions present on rib crests or posteriorly, developing into tiny calcified rugae on posterior slope. Anterior half of the shell densely granulated. Lunular heart very small. Exterior and

interior generally bright orange, but not uncommonly whitish with cream triangles with extensive reddish-brown maculations, becoming darker towards the umbo. In the whitish shells with cream triangles, a patch of orange is still visible near the inner posterior margin and in rib interstices of the posterior slope.

DISTRIBUTION AND ECOLOGY

The known distribution of *F. boholensis* is from Thailand, Vietnam, Philippines through to Indonesia. It occurs in shallow water (ter Poorten 2009).

REMARKS

The WA record of Vidal (1994), a yellow-orange specimen with white margins, could not be traced in the QM (personal commumication John Healy, 05.2012). This record is confirmed by the presence of another Dampier sample in the NTM collection. The species can easily be confused with *F. australis* and *F. aperta* (Bruguière, 1789), certainly when the typical bright orange colour variation is not present.

Fulvia hungerfordi (G.B. Sowerby III, 1901)

Figures 11M–O, 19D

Cardium (*Papyridia*) [sic! err. pro *Papyridea*] *hungerfordi* G.B. Sowerby III, 1901: pl. 9 fig. 5.

Fulvia (*Laevifulvia*) *prashadi* Vidal, 1994: 111–112, pl. 3 figs 8a–b.

Fulvia (*Laevifulvia*) *hungerfordi* (G.B. Sowerby III, 1901) — ter Poorten 2009: pl. 14 figs 5–8, pl. 15 figs 3–4; Huber 2010: 305, fig.; ter Poorten 2011: pl. 1110 figs 4–6.

MATERIAL EXAMINED

Australia: ***Northern Territory:*** **Groote**, N.W. coast of Gulf of Carpentaria, western side of Gove Peninsula, Melville Bay, 12°11.75'E, 136°41.28'E, 12–17 m, 19.03.1992. Leg. J.R. Hanley & party (NTM P.9284, 3 s.v.); **Arnhem Wessel**, central Arnhem Land, S.E. of Milingimbi settlement, 12°9.273'S, 134°57.930'E, 0.9 m, 05.12.2004. Leg. S.K. Horner, G.M. Dally & party (NTM P.37056, 1 s.v.); **Van Diemens Gulf**, western Arnhem Land, Kakadu National Park, N. of Field Island, 12°3.55'S, 132°23.44'E, 3 m, 23.11.2004. Leg. N. Smit (NTM P.32069, 5 s.v.); **Anson Beagle**, N.N.E. of Darwin, Shoal Bay, Gun Point Public Beach, 12°19.55'S, 131°0.8'E, 26.10.1997. Leg. R.C. Willan, J.D. Taylor & E.A. Glover (NTM P.10276, 3 s.v.); Darwin Harbour, Iron Ore Wharf, 12°28.22'S, 130°51.01'E, 6 m, 16.08.1998. Leg. C.L. Hewitt & party (NTM P.11700, 1 s.v.); E. side of Darwin Harbour, 1 nautical mile W. of Fannie Bay Beach, 'E' Buoy, 12°25.33'S, 130°49.03'E, 07.07.1993. Leg. R.S. Williams (NTM P.7260, 1 s.v.).

DESCRIPTION

Shell small (L 10–15 mm), thin, inflated, generally inequilateral with posterior third expanded and posterior margin truncated. Radial ribs strongly developed on posterior third, anteriorly less accentuated, obsolete on median part, which has a glossy and smooth appearance. Dense granulations can be present, often limited to posterior quarter of the shell and near the ventral margin. Internal marginal crenulations usually weakly defined in the mid ventral margin edge, well developed towards anterior and posterior margin and visible over a long distance from the margins. Lunular heart small. Exterior and interior colour uniform whitish to reddish brown, adults sometimes with concentric growth lines visible as a change in shell colour and opacity.

Distribution and ecology — Not encountered in WA, but present in the continental coastal waters of NT (Figure 19D). Found in shallow water (depth range 0–17 metres, based on dead recordings). Two samples from Kurrimine Beach, QLD (WAM S78275, 4 s.v.) and central NSW (NTM P.36678, 1 p.v., Figure 11M) have also been located. To date, the species has not been reported from Australia. It is widely distributed in the Central IWP, has a marked tolerance for turbid and polluted waters (Shin 1985: Tolo Harbour, Hong Kong; Madang Harbour, Papua New Guinea, MNHN colln) and prefers sheltered, muddy habitats.

REMARKS

Fulvia hungerfordi has likely been overlooked due to its small size, fragile shell and superficial similarity with other congeners. It is also known from southern Indonesia, Sumba (ZMA, Siboga Exped., Stn 53, 4 s.v., det. TP). It is likely that other small *Fulvia* species occur in the northern half of Australia but as yet have not been recognised.

Fulvia laevigata (Linnaeus, 1758)

Figures 11E–F, 19E

Cardium laevigatum Linnaeus, 1758: 680.

Cardium papyracea, testa cordata, [...] Chemnitz, 1782: 190, pl. 18 fig. 184 (rejected work, Direction 1 ICZN).

Cardium papyraceum Schröter, 1788: 19 (*non* binominal).

Cardium papyraceum Bruguière, 1789: 231.

? *Cardium pallidum* Reeve, 1845: sp. 92, pl. 18 fig. 92.

Fulvia voskuili Healy & Lamprell, 1992: 89–91, pl. 4 figs a–d.

Fulvia sp. — Lamprell & Whitehead 1992: pl. 34 fig. 226 [= holotype of *Fulvia voskuili* Healy & Lamprell, 1992; jun. syn. of *Cardium laevigatum* Linnaeus].

Fulvia (*Fulvia*) *papyracea* (Bruguière, 1789) — Lamprell and Healy 1998: 256.

Fulvia (*Fulvia*) *laevigata* (Linnaeus, 1758) — ter Poorten 2009: pl. 12 figs 1–5, pl. 15 fig. 1; Huber 2010: 304, fig.; ter Poorten 2011: pl. 1109 figs 3–5.

MATERIAL EXAMINED

Australia: ***Northern Territory:*** **Groote**, Groote Eylandt, pre 09.07.1968 (WAM S78181, 3 p.v.); NW. coast of Gulf of Carpentaria, Gove Peninsula, near Nhulunbuy, Town Beach point, 12°11'S, 136°47'E, 17.07.1996. Leg. F.W. McGreevy (NTM P.52681, 1 s.v.); S. end of Turtle Beach, 12°11'S, 136°47'E, 21.07.1996. Leg. F.W. McGreevy (NTM P.41556, 1 s.v.); beach immediately adjacent to Port Bradshaw, 12°32.75'S, 136°44.35'E, 06.07.1994. Leg. K. Colgan (NTM P.4358, 1 p.v., 12 s.v.); W. side of Gove Peninsula, Melville Bay, 12°15'S, 136°43'E, 12–17 m, 07.1991. Leg. J.R. Hanley & party (NTM P.37537, 1 p.v., 2 s.v.); W. side of Gove Peninsula, N. coast of Melville Bay, sandy beach immediately S.E. of Alcan Aluminium Refinery, 12°11.347'S, 136°41.879'E, 04.09.2007. Leg. S.M. Gregg (NTM P.40663, 2 s.v.); **Arnhem Wessel**, eastern Arnhem Land, NW. coast of Elcho Island, 11°48.277'S, 135°53.062'E, 23.07.2008. Leg. A. Beatty & J. Damaso (NTM P.41842, 3 s.v.); central western coast of Elcho Island, immediately N. of Galiwinku, Duduhpu (= First Creek), 11°59.951'S, 135°34.267'E, 08.06.2011. Leg. D.G. Freier (NTM P.50883, 1 s.v.); central Arnhem Land, Millingimbi, approx. 260 m S. of Mjrungga Island, 11°57.345'S, 135°5.657'E, 5.2 m, 04.12.2004. Leg. S.K. Horner, G.M. Dally & party (NTM P.30064, 1 p.v., A); Boucaut Bay, Yilan, 12°1.7'S, 134°38.200'E, 19.10.1994. Leg. C. Coleman (NTM P.6899, 2 s.v.); N. of Maningrida, mouth of Liverpool River, 12°1.165'S, 134°14.645'E, 2.7 m, 02.12.2004. Leg. S.K. Horner, G.M. Dally & party (NTM P.37155, 1 s.v.); Maningrida, 12°03'S, 134°13'E, 08.1993. Leg. C. Coleman (NTM P.7146, 3 s.v.); Maningrida, 12°03'S, 134°13'E, 01.1980. Leg. B. Ether (NTM P.7034, 5 s.v.); **Cobourg**, South Goulburn Island, approx. 2 km E. of McPherson Point, 11°38.730'S, 133°26.386'E, 1 m, 29.11.2004. Leg. S.K. Horner, G.M. Dally & party (NTM P.31275, 1 p.v., A); N.W. extremity of Arnhem Land, central eastern coast of Croker Island, Minjilang, 11°9.1020'S, 132°34.902'E, 08.08.2008. Leg. H.K. Larson & S. Hoeng (NTM P.41917, 1 s.v.); N. coast of Cobourg Peninsula, mid-eastern coast of Port Essington, N. side of Table Head, 11°14.5'S, 132°11'E, 14.09.1998. Leg. L.K. Gravener (NTM P.11350, 1 p.v., 4 s.v.); Port Essington, Record Point, 11°19'S, 132°10.3'E, 1969. Leg. H. Blackburn (NTM P.5221, 1 p.v.); Port Essington, mouth of Caiman Creek, 11°21'S, 132°06'E, 18.09.1985. Leg. P.N. Alderslade (NTM P.54158, 1 p.v.); S.W. section of Port Essington, margin of islet just N. of Minto Head, 11°11'S, 132°03.4'E, 12.08.1986. Leg. R.C. Willan (NTM P.1831, 2 s.v.); Port Essington, 5 nautical miles N.W. of Smith Point, western end of Orontes Reef, 11°04'S, 132°03'E, 17 m, 09.08.1986. Leg. R.C. Willan (NTM P.32020, 2 s.v.; NTM P.54201, 2 p.v., 1 s.v.); Port Essington, Coral Bay, off small Island at S. end of Bay, 11°11'S, 132°03'E, 0–8 m, 11.08.1986. Leg. S.M. Slack-Smith, Stn CP#96 (WAM S78180, 1 p.v.); Vashon Head, 11°08'S, 132°0'E, 1969. Leg. H. Blackburn (NTM P.713, 2 p.v.); **Van Diemens Gulf**, Port Essington & Cobourg Peninsula, 11°28'35.25"S, 132°18'31.97"E, 1969. Leg. H. Blackburn (WAM S78189, 4 p.v.); **Anson Beagle**, N. of Darwin, N. of Lee Point, 12°18.84'S, 130°52.86'E, 10 m, 11.10.1993. Leg. A.Y. Williams (NTM P.4436, 1 s.v.); N. of Darwin, Lee Point, 12°19'S, 130°54'E, 16.08.1992. Leg. R.C. Willan (NTM P.14900, 1 s.v.); Lee Point, 12°19'S, 130°54'E, 29.09.1992. Leg. R.C. Willan, M.M. Burke & A.E. Wells (NTM P.23167, 1 s.v.); Lee Point, 12°19'S, 130°54'E, 28.02.1993. Leg. R.C. Willan & A.W. Klishans (NTM P.41003, 1 s.v.); Lee Point, 12°19'S, 130°54'E, 18.07.2006. Leg. R.C. Willan & R. Burn (NTM P.38353, 1 s.v.); Lee Point, 12°19'S, 130°54'E, sandy beach, 03.2005. Leg. M. Huber (TP 2278, 3 s.v.); Lee Point, 12°19'S, 130°54'E, 13.07.2014. Leg. J.J. ter Poorten & R.C. Willan (TP 4464, 4 s.v.); Darwin, Shoal Bay, Tree Point, 12°19.55'S, 131°0.8'E, 10.11.1984 (TP 2131, 3 p.v.; NMR 20206, 1 p.v.); Tree Point, 12°19.55'S, 131°0.8'E, 26.10.1997. Leg. R.C. Willan, J.D. Taylor & E.A. Glover (NTM P.10733, 2 p.v.); western section of Gunn Point Beach, 12°14.8'S, 131°1.7'E, 30.12.1992. Leg. A.W. Klishans (NTM P.19526, 1 s.v.); mouth of Howard River, 12°19.05'S, 131°0.08'E, 20.12.1992. Leg. R.C. Willan & G. Robertson (NTM P.32626, 4 s.v.); Darwin, central section of Casuarina Beach, 12°21'S, 130°53.03'E, 02.1993. Leg. R.C. Willan (NTM P.30734, 3 s.v.); 12°21'S, 130°53.03'E, 04.1993. Leg. R.C. Willan (NTM P.24793, 1 s.v.); 12°21'S, 130°53.03'E, 10.1993. Leg. R.C. Willan (NTM P.2817, 4 p.v.); 12°21'S, 130°53.03'E, 02.1994. Leg. R.C. Willan (NTM P.3543, 1 p.v.); 12°21'S, 130°53.03'E, 01.1995. Leg. R.C. Willan (NTM P.6269, 2 s.v.); 12°21'S, 130°53.03'E, 12.1995. Leg. R.C. Willan (NTM P.8110, 3 p.v., 6 s.v.); 12°21'S, 130°53.03'E, 08.04.1996. Leg. R.C. Willan & M.E. Chaddock (NTM P.9957, 1 p.v., 3 s.v.); 12°21'S, 130°53.03'E, 02.1998. Leg. R.C. Willan (NTM P.10578, 1 p.v., 4 s.v.); 12°21'S, 130°53.03'E, 11.1999. Leg. R.C. Willan (NTM P.13696, 3 p.v., 7 s.v.); 12°21'S, 130°53.03'E, 06.2000. Leg. R.C. Willan (NTM P.17293, 17 p.v.); 12°21'S, 130°53.03'E, 03.2002. Leg. R.C. Willan (NTM P.19683, 1 p.v.); 12°21'S, 130°53.03'E, 03.2004. Leg. R.C. Willan (NTM P.27733, 2 p.v.); 12°21'S, 130°53.03'E, 06.2004. Leg. R.C. Willan (NTM P.32883, 2 p.v.); 12°21'S, 130°53.03'E, 06.2007. Leg. R.C. Willan

(NTM P.45131, 3 p.v., 3 s.v.); Casuarina Beach, Dripstone Caves area, 12°21.08'S, 130°51.08'E, 05.08.1992. Leg. R.C. Willan (NTM P.14998, 5 s.v.); 12°21.08'S, 130°51.08'E, 10.1992. Leg. R.C. Willan (NTM P.8361, 4 s.v.); 12°21.08'S, 130°51.08'E, 12.1992. Leg. R.C. Willan (NTM P.14705, 7 s.v.); Darwin, Vesteys Beach, southern end of Fannie Bay, 12°26.2'S, 130°49.4'E, sandy beach, 14-17.07.2014/ Leg. J.J. ter Poorten (TP 4466, 1 s.v.); Darwin, Nightcliff, 12°23'S, 130°50'E, 09.1990. Leg. A. Klishands (WAM S78167, 1 s.v.); Darwin Harbour, northern end of Fannie Bay, 12°25.1'S, 130°49.6'E, 1.5 m, 07.07.1993. Leg. R.S. Williams (NTM P.24527, 1 p.v.); Darwin Harbour, 200 metres SW. of Dudley Point, "Dudley Bommies" dive site, 12°25'S, 130°48.4'E, 4 m, 12.08.1992. Leg. R.C. Willan (NTM P.16350, 1 s.v.); Darwin Harbour, W. side of entrance to West Arm, rocky/coral reef S.E. of Swires Bluff, 12°31.2'S, 130°47.6'E, 08.10.1994. Leg. R.C. Willan (NTM P.19207, 2 p.v.); Darwin Harbour, S.E. edge of East Point Reef, 12°25'S, 130°47'E, 8 m, 27.07.1992. Leg. R.C. Willan (NTM P.29986, 1 s.v.); Darwin Harbour, East Point, 12°25'S, 130°47'E, 28.09.1992. Leg. R.C. Willan & M.M. Burke (NTM P.14023, 2 p.v.); Darwin Harbour, East Arm, off breakwall to East Arm Port, 12°29.51'S, 130°52.98'E, 4 m, 21.08.1998. Leg. R.C. Willan (NTM P.11225, 1 s.v.); Darwin Harbour, East Arm, 12°30'S, 130°54'E, 23.12.1995. Leg. A. Klishands (WAM S78179, 1 p.v.); Darwin Harbour (TP 955, 1 p.v.); Darwin Harbour, NW. of Wickham Point, 12°30.3'S, 130°50.5'E, 7 m, 14.07.1993. Leg. R.S. Williams (NTM P.24550, 2 s.v.); Darwin, 09.1987. Leg. C.C. Nengerman (ZMA. MOLL.106337.1); S.E. coast of Bynoe Harbour, W. of Dawson Rock, 3 km S.E. of Rankin Point, 12°42.207'S, 130°35.459'E, 6–7 m, 27.04.2007. Leg. R.C. Willan (NTM P.38438, 1 p.v.); **Tiwi**, N.W. tip of Melville Island, coast 4 km E. of Cape Van Diemen, 11°10.5'S, 130°24.5'E, 28.09.1996. Leg. R.C. Willan (NTM P.8906, 3 s.v.); N.W. coast of Melville Island, sand dunes at Piper Head, mouth of Apsley Strait, 11°16'S, 130°22.55'E, 06.06.1999. Leg. J.A. Risler (NTM P.12219, 1 s.v.); off NW. tip of Melville Island, Mermaid Straits, 8 km NW. of Cape Van Diemen, Pirritadirri (= Seagull Island), 11°6.66'S, 130°19.809'E, 28.09.1996. Leg. R.C. Willan (NTM P.9105, 1 s.v.).

Australia: ***Western Australia:*** **Bonaparte Gulf**, Tranquil Bay, 13°56'S, 127°18'E, intertidal rocks, 0–1 m, 13.08.1991. Leg. C.W. Bryce, WAM Kimberley Islands & Reefs Survey 1991, Stn 4 (WAM S56805, 1 p.v.); Kimberley, Malcolm Island, 14°31'S, 125°54'E, 31.10.1976, Leg. F.E. Wells, WAM Admiralty Gulf Mangal Survey 1976 (WAM S66947, 1 s.v.); Institut Islands, Corneille Island, 14°11'18"S, 125°43'58"E, 19.07.1988, Leg. F.E. Wells & C.W. Bryce (WAM S56824, 2 p.v.); Coronation Islands, 14°58'S, 124°55'E, 28.08.1971. Leg. L.A. Smith (WAM S56804, 1 s.v.); **Canning**, S. of Roebuck Bay, Admiral Bay, Cape Bossut, Paspaley Company operations dump site for pearl shells, 18°48'S, 121°31'E, 23.11.1993. Leg. A.Y. Williams (NTM P.21220, several p.v.); **Pilbara Nearshore/Offshore**, Montebello Islands, Main Bay, Trimouille Island, 20°24'13"S, 115°34'05"E, 23.08.1993. Leg. S.M. Slack-Smith, WAM Montebellos Islands Survey 1993, Stn MB/93/32B (WAM S84239, 1 p.v., A); 'Pilbara Coast'. Leg. B. & J. Ball (WAM S70893, 3 p.v., 7 s.v.); Shark Bay, Dirk Hartog Island, Leg. A. Bassett, ex coll. P.L. van Pel (ZMA.MOLL.80974, 1 p.v.); South Passage, in sand and weed, 3–5 m, 2001. Leg. H. Morrison (TP 1166, 2 p.v.); South Passage, in sand and rubble, 5–10 m, 03.1999. Leg. H. Morrison (TP 4456, 1 p.v.); Steep Point, 26°09'S, 113°09'E, 03.1986. Leg. F.E. Wells & C.W. Bryce (WAM S66948, 1 p.v.); Peron Peninsula, Broadhurst Bight, circa 3 miles offshore, 8 m, 21.02.1982. Leg. P.L. van Pel (ZMA.MOLL.80875, 1 p.v.); Monkey Mia, 09.1987. Leg. P.L. van Pel (ZMA. MOLL.80911).

DESCRIPTION

Shell large (L 40–55 mm), rather thin and fragile, equilateral and almost circular. Some specimens with slight posterior elongation. Between 33–48 small and weakly developed radial ribs. Interstices wide and flat. Lunule large with small lunular heart. Exterior tan, lilac posteriorly and a deep purple umbonal tip, occasionally yellow with brown zigzag lines. Interior generally much deeper coloured than exterior, often with purple posterior half and regularly concentric purple stripes with a white or yellowish umbonal cavity and a radial purple stripe. Periostracum thick, along posterior sides of the ribs, absent on anterior sides.

DISTRIBUTION AND ECOLOGY

In WA and NT, *Fulvia laevigata* is typically confined to continental coastal waters (Figure 19E) and is very common in the Darwin area. It is found in turbid shallow water and it seems to inhabit protected littoral habitats like bays, lagoons and estuaries with soft bottoms (ter Poorten 2009). It is widely distributed in the Central IWP.

REMARKS

This species has likely been mistaken for the superficially similar *Fulvia aperta* (Bruguière, 1789). Wilson and Stevenson (1977: 53–54) observed this similarity, suggesting that *Cardium papyraceum* Bruguière, 1789 might be a junior synonym of *F. aperta*. However, Vidal (1994) argued that two different species are involved and demonstrated (Vidal 1999) that *F. papyraceum* must be considered a junior synonym of *F. laevigata* (Linnaeus, 1758). The Shark Bay samples are the southernmost records. It is also known from the southern Indonesian Roti Island (ZMA, Siboga Exped., Stn 299, 1 p.v., det. TP), taken from a mud bottom.

Fulvia scalata Vidal, 1994

Figures 11P–T, 19F

Fulvia (*Fulvia*) *scalata* Vidal, 1994: 108–109, pl. 1 figs 3–4, pl. 3 figs 5a–b, 7.

Fulvia (*Fulvia*) *scalata* Vidal, 1994 — Lamprell and Healy 1998: 246, fig. 741; ter Poorten 2009: pl. 13 figs 8–10, pl. 15 fig. 2; Huber 2010: 305, fig.; ter Poorten 2011: pl. 1110 figs 7–8.

MATERIAL EXAMINED

Australia: ***Western Australia:*** **North West Shelf**, Rowley Shoals, S.E. of Mermaid Reef, 17.4872°S, 120.4606°E to 17.4954°S, 120.4679°E, 184–187 m, 20.06.2007. Leg. C. Whisson & O. Gomez, CSIRO RV 'Southern Surveyor' Cruise, Stn SS0507/091 (WAM S34673, 5 s.v.); 100 miles N.W. of Port Hedland, 18°47'S, 117°58'E, 154 m, 28.03.1982. Leg. L.M. Marsh, CSIRO FRV 'Soela' Cruise II 1982, Stn SO2/82/10A (WAM S56827, 1 s.v.; WAM S57158, 16 s.v.).

Literature records: Vidal (1994): Dampier (QM, 1); ALA / OZCAM: 71 nautical miles N.N.W. of Dampier (AMS C.172915, det. J. Vidal).

DESCRIPTION

Shell small (L 15–21 mm), rather thin, rounded to subquadrangular, inflated, roughly equilateral. Between 40–45 well delimited radial ribs, particularly on posterior third of the shell. Commarginally aligned granules present in the interstices of the anterior and posterior slopes, close-set and placed like steps of a ladder — hence the species' name. Periostracal insertions rather weak, mainly on the posterior limit of the ribs. Very large and broad lunular heart. Exterior and interior generally uniform pale brown to pinkish, often evenly covered with slightly darker maculations.

DISTRIBUTION AND ECOLOGY

Consistent with other non-Australian records that indicate a wide geographic range and affinity for deep water, the WA records of *Fulvia scalata* were found close to the continental shelf edge off the northern coast (depth range 154–187 m, based on single valves; Figure 19F). This species is also reported from QLD (Vidal 1994; WAM S78360) and the Gulf of Carpentaria (Vidal 1994; Lamprell and Healy 1998). It is a tropical deep water species, widely distributed in the IWP.

REMARKS

The typical ladder-like sculpture present in the interstices of the posterior slope and the relatively well developed radial ribs on the posterior slope, easily differentiate this species from its congeners. The holotype is figured for comparison (MNHN-IM-2000-4021, Figure 11T).

Fulvia undatopicta (Pilsbry, 1904)

Figures 11U–Y, 19G

Cardium hungerfordi undatopictum Pilsbry, 1904: 556, pl. 40 figs 14–15.

Cardium hungerfordi stigmaticum Pilsbry, 1904: 556–557, pl. 41 figs 13–14.

Fulvia (*Fulvia*) *undatopicta* (Pilsbry, 1904) — Lamprell and Healy 1998: 246, fig. 742.

Fulvia (*Laevifulvia*) *undatopicta* (Pilsbry, 1904) — ter Poorten 2009: pl. 14 figs 1–4; Huber 2010: 305, fig.; ter Poorten 2011: pl. 1110 figs 1–2.

MATERIAL EXAMINED

Australia: ***Western Australia:*** **Canning**, W. of Broome, 17°58'S, 122°14'E, 90 m, 21.12.1969. Leg. K. Ozawa, Tokyo University of Fisheries Exped. FV 'Umataka Maru', Stn UMD6927 (WAM S57166, 1 s.v.); **Pilbara Offshore**, 38 nautical miles N. of Port Walcott, 19°59'S, 117°16'E to 20°01'S, 117°16'E, 50–52 m, 15.04.1982. Leg. L.M. Marsh, CSIRO FRV 'Soela' Cruise II, Stn SO2/82/54A (WAM S78297, 1 s.v.); Exmouth Gulf, 14 km E. of Muiron Islands, Hawksbill Exploration Field, 21°41'S, 114°31'E, 15 m, 05.12.1993. Leg. Apache Energy (WAM S78338, 1 p.v., A).

Literature records: Vidal (1994): Gulf of Carpentaria (AMS, 1).

DESCRIPTION

Shell small (H 10–19 mm), thin, roughly equilateral and rounded ovate, a little truncated posteriorly; height generally slightly exceeds length. Between 46–53 radial ribs; a few strong ribs on posterior part of the shell, weak anteriorly, almost smooth elsewhere. Scattered granulations present, often more or less commarginally aligned, especially on antero-ventral part of the shell. Internal marginal crenulations usually clearly defined. Lunular heart rather small, elongated. Colour extremely variable, often whitish with irregular reddish brown streaks or spots, at times with four reddish spots or streaks forming a cross.

DISTRIBUTION AND ECOLOGY

All three samples of this wide-ranging tropical IWP species come from the northern coastal area of WA (Figure 19G) in 15–90 metres depth (found alive at 15 metres depth). This species is known from QLD and the Gulf of Carpentaria (Vidal 1994; Lamprell and Healy 1998) but so far has not been recorded from WA.

REMARKS

The presence in the Gulf of Carpentaria is based on a historical sample (AMS C.15313, 16°58'S, 140°53'E, 05.06.1903. Leg. C. Hedley, det. J. Vidal) and needs to be confirmed by more recent finds.

The subgenus *Laevifulvia* Vidal, 1994 has been shown to be paraphyletic with recent molecular research (Herrera et al. 2015) demonstrating that *F. undatopicta* is well rooted in a clade with other *Fulvia* species, whereas *F. hungerfordi*, also placed in subgenus *Laevifulvia* by Vidal (1994), forms a separate clade. Recently, *Laevifulvia* was synonymised with *Fulvia* by ter Poorten and Hylleberg (2017), based on morphological characters.

Genus *Laevicardium* Swainson, 1840

Laevicardium Swainson, 1840: 373 (as a subgenus of *Cardium*). Type species by subsequent designation (Stoliczka, 1870: xviii, 209): *Cardium oblongum* Gmelin, 1791; Recent, 'mari mediterraneo' ('Mediterranean').

Liocardium Agassiz, 1846: 199, 212 (unnecessary emendation of *Laevicardium* Swainson, 1840).

'Laevicardium' lobulatum (Deshayes, 1855)

Figures 7N–U

Cardium lobulatum Deshayes, 1855: 332.

Laevicardium multipunctatum (Sowerby in Broderip & Sowerby, 1833) — Lamprell and Whitehead 1992: pl. 33 fig. 223.

Fulvia (*Laevifulvia*) *imperfecta* Vidal & Kirkendale, 2007: 92–93, figs 3j–l.

Laevicardium lobulatum (Deshayes, 1855) — Huber 2010: 303, fig.

'Laevicardium' lobulatum (Deshayes, 1855) — ter Poorten 2009: pl. 14 figs 15–18, pl. 15 figs 5–6; pl. 16 figs 13–15; ter Poorten 2011: pl. 1114 figs 1–3.

MATERIAL EXAMINED

Australia: ***Western Australia:*** **Oceanic Shoals**, Rowley Shoals, Clerke Reef, 17°17'51.826"S, 119°21'32.899"E, 15 m, lagoon (patch reef), 07.10.2014. Leg. L. Kirkendale & C. Bryce, Woodside Kimberley Survey 2014, Stn 155/K14 (WAM S68164, 1 p.v., A).

DESCRIPTION

Shell medium sized (H 25–35 mm), rather solid, inequilateral, elongately oblique. Juveniles more rounded-quadrangular, less inflated and relatively thin. Margins rounded, except for a short posterior straightening or indentation, better developed in adults. Shell surface glossy and smooth with minute growth lines. On the medio-posterior part these lines are crossed by approximately six weakly developed ribs, creating a finely undulating pattern. Internal margin carrying about 70–95 crenulations. Lunule elongate, slightly protruding. Hinge long and arched. Exterior cream with brown radial or inverted v-shaped markings, occasionally with a zigzag pattern and with margins usually lighter coloured. Interior often darker reddish-brown. Hinge plate chocolate brown to purple. A well developed pattern with differences in translucency is present in the juvenile stage (Figures 7N–Q).

DISTRIBUTION AND ECOLOGY

This juvenile live-taken specimen from the oceanic emergent reefs is the first WA record of this species. The lagoonal occurrence is in line with the other records from sheltered shallow water habitat in bottoms of sand, silt and mud. Also known from QLD (Hedley 1909, 1910; WAM, NTM, AMS colln) and widely distributed in the Central IWP.

REMARKS

For comparison, figures of the three syntypes are given (NHMUK 1974135, Figures 7R–U). Recent molecular phylogenetic research by Herrera et al. (2015) demonstrates that this species is unrelated to other species in the genus *Laevicardium,* as first noted by ter Poorten (2009), who identified this discrepancy based on differences in microsculptural details. Together with *Fulvia lineonotata* Vidal, 1994, these two species currently represent a distinct lineage, superficially similar to other *Laevicardium* based on gross shell shape, but unrelated as indicated by molecular work and subtle morphological characters. The adjusted generic assignment will be presented elsewhere. The 'smooth' appearance is likely due to convergent evolution, having evolved in separate lineages as adaptations to a similar lifestyle (of burrowing) and a misleading character for phylogenetic inference.

Subfamily Trachycardiinae Stewart, 1930

REMARKS

Based on molecular analysis, Trachycardiinae forms a monophyletic group (Herrera et al. 2015), confirming earlier findings by Keen (1969) and Schneider and Carter (2001), based on shell morphology and microstructure, respectively. Only two genera: *Acrosterigma* and *Vasticardium* occur in the study area covered in this paper.

Genus *Acrosterigma* Dall, 1900

Acrosterigma Dall, 1900: 1073, 1090 (as a section of *Trachycardium*). Type species by original designation: *Cardium dalli* Heilprin, 1887; Caloosahatchee Formation, Pliocene, Florida, U.S.A.

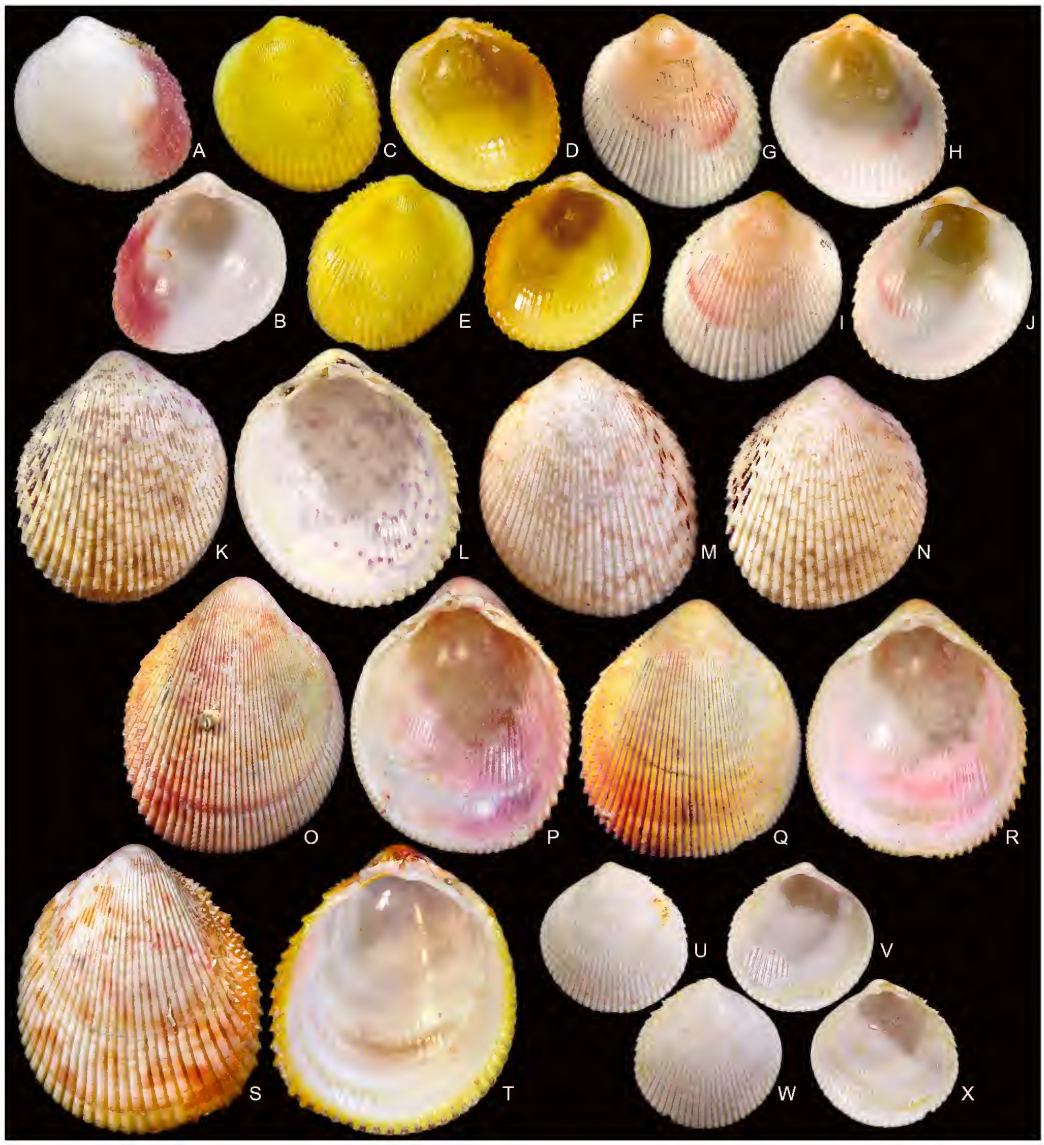

FIGURE 12 A, B, C, D, E, F, G, H, I, J, *Acrosterigma dianthinum* (Melvill & Standen, 1899). A–B, Ashmore Reef, WA: WAM S91665, length 8.2 mm. A, exterior of l.v., B, interior of l.v.; C–F Vulcan Shoal, WA, WAM S91854, length 7.9 mm. C, exterior of l.v., D, interior of r.v., E, exterior of r.v., F, interior of l.v.; G–J, Torres Strait, QLD: NHMUK 1899.2.23.11, syntype, height 13.7 mm. G, exterior of l.v., H, interior of r.v., I, exterior of r.v., J, interior of l.v.

K, L, M, N, *Acrosterigma punctolineatum* Healy & Lamprell, 1992. K–L, Yankawingarri Island, WA: WAM S56950, height 30.6 mm. K, exterior of l.v., L, interior of l.v.; M, Largest of the three possible syntypes of *Cardium foveolatum* G.B. Sowerby II, 1840, 'Swan River', WA [erroneous]: NHMUK 1996514, height 32.0 mm, exterior of l.v.; N, Condillac Island, WA: WAM S56949, height 28.6 mm, exterior of r.v.

O, P, Q, R, *Acrosterigma suduirauti* Vidal & ter Poorten, 2007. Rowley Shoals, WA: WAM S32883. O–P, height 37.5 mm, Q–R, height 31.5 mm; O, exterior of r.v., P, interior of r.v., Q, exterior of r.v., R, interior of r.v.

S, T, *Acrosterigma variegatum* (G.B. Sowerby II, 1840). Ningaloo Marine Park, WA, WAM S43505, height 56.6 mm. S, exterior of l.v., T, interior of l.v.

U, V, W, X, *Acrosterigma simplex* (Spengler, 1799). Montebello Islands, WA, WAM S78358, height 4.2 mm. U, exterior of l.v., V, interior of l.v., W, exterior of r.v., X, interior of r.v.

Acrosterigma dianthinum (Melvill & Standen, 1899)

Figures 12A–J, 20A

Cardium (*Trachycardium*) *dianthinum* Melvill & Standen, 1899: 190, pl. 11 figs 25, 25a.

Arosterigma dianthinum (Melvill & Standen, 1899) — Lamprell and Whitehead 1992: pl. 30 fig. 195 [= NHMUK 1899.2.23.11 syntype].

Acrosterigma dianthinum (Melvill & Standen, 1899) — ter Poorten 2009: pl. 1 figs 6–8; ter Poorten 2011: pl. 1088 figs 1–2.

MATERIAL EXAMINED

Australia: ***Western Australia:*** **Oceanic Shoals**, Vulcan Shoal, 12°47'57.481"S, 124°16'00.205"E, 19 m, 06.10.2013. Leg. L. Kirkendale & C. Bryce, Woodside Kimberley Survey 2013, Stn 146/K13 (WAM S91854, 1 p.v.); E. end, 12°14'37.282"S, 123°14'37.286"E, 15 m, 01.10.2013. Leg. L. Kirkendale & C. Bryce, Woodside Kimberley Survey 2013, Stn 135/K13 (WAM S91666, 1 s.v.; WAM S91667, 1 s.v.); E. side, 12°12'27.901"S, 123°08'44.268"E, 15 m, 03.10.2013. Leg. L. Kirkendale & C. Bryce, Woodside Kimberley Survey 2013, Stn 140/K13 (WAM S91668, 2 p.v., A); S. side, 12°17'36.6"S, 123°07'25.441"E, 12 m, 28.09.2013. Leg. L. Kirkendale & C. Bryce, Woodside Kimberley Survey 2013, Stn 128/K13 (WAM S91665, 1 s.v.); S. Scott Reef, outer slope, Sandy Islet, N. side, 14°02.526'S, 121°45.688'E, 6–13 m, 20.09.2006. Leg. C. Bryce & C. Whisson, WAM NWA Shelf Atolls Survey September 2006, Stn 22 (WAM S31136, 1 s.v.).

DESCRIPTION

Shell small (L 10–15 mm), rather thin, very inequilateral, transversally ovoid, and moderately inflated. Between 42–50 flat and low radial ribs, most anterior ones finely ornamented with scales, most posterior ones spined. Ribs possessing characteristic, regularly disposed granules on their tops, visible under magnification and skimming light. Lunule small and elongate. External coloration uniformly white to cream, often with scattered brownish blotches, posterior part often purple, ligamental nymph and umbonal cavity orange-yellow. Internal coloration similar by transparency.

DISTRIBUTION AND ECOLOGY

All WA records of this species are from the northern offshore reefs (Figure 20A). This small species is well known throughout the Central and Western Pacific, as indicated by records from the Coral Triangle up to Vanuatu, New Caledonia and across southern QLD. *Acrosterigma dianthinum* has been repeatedly collected alive in sandy shallow water environments among corals.

REMARKS

WAM S91854 (Figures 12C–F) is an atypical and monochromatic yellow-coloured specimen, a coloration that occasionally occurs in other genera as well, with examples known from *Afrocardium* (Figure 7H), *Corculum, Fragum, Frigidocardium, Fulvia, Pratulum, Tridacna* and *Vasticardium*.

Acrosterigma extremattenuatum sp. nov. ter Poorten & Kirkendale

Figures 13A–H, 14, 20B

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Laevicardium attenuatum (Sowerby, 1841) — Habe and Kosuge 1970: 154, pl. 59 fig. 10.

Laevicardium attenuatum (Sowerby, 1841) — Wilson and Stevenson 1977: 57–59, pl. 3 fig. 12, text fig. 6 [*pars*].

Laevicardium attenuatum (Sowerby, 1840) — Lamprell and Whitehead 1992: pl. 33 fig. 221, cover fig.

Acrosterigma attenuatum (Sowerby, 1841) — Vidal 1999: 327–329, fig. 20 [*pars*].

MATERIAL EXAMINED

Holotype

Australia: ***Western Australia:*** **Pilbara Offshore**, 7 miles N. of Long Island, off Onslow, 21°31'S, 114°40'E, fine sand and rubble, 51.2 m, 17.06.1960. WA Hawaiian Exped. (WAM S84456, ex 1067-66 [shell] / 1076-66 [label], 1 s.v.).

Paratypes

Australia: ***Northern Territory:*** **Arafura Sea**, off Darwin. Ex coll. A.R. Cahn, 1958 (ANSP 219279, 1 p.v., paratype).

Australia: ***Western Australia:*** **Pilbara Offshore**, East Pilbara, Port Hedland-De Grey River mouth area. Leg. M. Claydon (TP 4460, 1 p.v., paratype); E. of Dampier, Nickol Bay, trawled by shrimper, c. 30 m (RMNH.5004012, 1 p.v., paratype); 7 miles N. of Long Island, off Onslow, 21°31'S, 114°40'E, fine sand and rubble, 51.2 m, 17.06.1960. WA Hawaiian Exped. (WAM S66298, ex 1067-66 [shell] / 1076-66 [label], 1 s.v., paratype); **Ningaloo**, off Osprey Reef, 22°10.279'S, 22°10.489'S, 113°49.163'E-113°49.103'E, epibenthic sled, sand, 71.4–73.0 m, 28.04.2006. Leg. M.P. Salotti, AIMS-WAM RV 'Cape Ferguson' Ningaloo Survey I April/May 2006, Stn CF4010&11/2006/D013 (WAM S84454, 1 s.v., paratype).

Other materials

Australia: ***Queensland:*** 'off Lucinda, trawled 60–80 m' [locality questionable] (S. Hobbs, U.S.A., 2 p.v.); **Torres Strait**, Torres Strait Biodiversity, Stn TS80006631, (QM, 1 p.v., A); **Wellesley**, S.E. corner of

FIGURE 13 A, B, C, D, E, F, G, H, *Acrosterigma extremattenuatum* sp. nov. A–D, off Onslow, WA. A–C, WAM S84456, holotype, H 46.5 mm. A, exterior of r.v., B, interior of r.v., C, hinge of r.v.; D, WAM S66298, paratype, height 32.3 mm, exterior of r.v.; E–F, Ningaloo Marine Park, WA: WAM S84454, paratype, height 60.8 mm. E, exterior of l.v., F, anterior; G–H, Port Hedland-De Grey River mouth area, WA, TP 4460, paratype, height 54.8 mm. G, exterior of l.v., H, posterior.

I, J, K, L, M, N, *Acrosterigma attenuatum* (G.B. Sowerby II, 1841). I, Aru, Indonesia, WAM S67690, height 35.0 mm, exterior of r.v.; J–N, 'Ceylon' (description), 'Ceylon, Zanzibar, Philippines' (label): NHMUK 197126, lectotype, height 77.0 mm. J, exterior of l.v., K, interior of r.v., L, anterior, M, posterior, N, hinge of r.v.

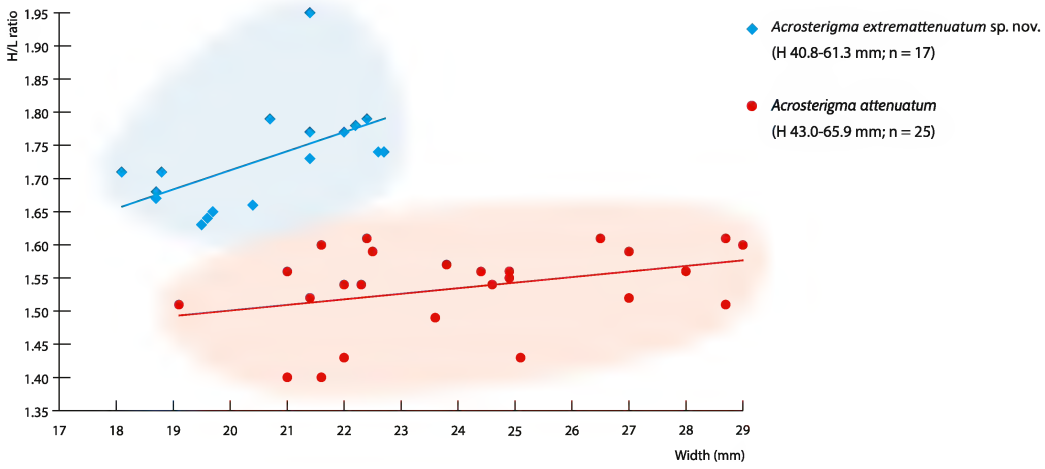


FIGURE 14 Scatter diagram showing the relation of shell width (horizontal axis) and H/L ratio (vertical axis) for *Acrosterigma extremattenuatum* sp. nov. (blue diamonds, n = 17) and *A. attenuatum* (red circles, n = 25). Only (sub)adult shells are plotted, defined as all those individuals with a height of at least 40 mm. Colln ANSP, MNHN, WAM, TP, UF, ZMA, S. Hobbs, E. Kaptein and H. van Rij.

Gulf of Carpentaria, 16°19'25.0"S, 139°09'10.0"E, trawl, 20 m, 22.02.1965. Leg. CSIRO Fisheries, CSIRO 'Rama' Gulf of Carpentaria Prawn Survey 1965, Stn RAMA #1782 (WAM S84465, 1 s.v.; WAM S84231, 1 p.v., A).

Australia: ***Northern Territory:*** **Arafura Sea**, by Taiwan fishing boats. Ex coll. Lan (UF 472551, 1 p.v.)

Australia: ***Western Australia:*** **Canning**, 10–20 miles W. of Lagrange Bay, 18°39'S, 121°42'E, dredged, 20–45 m, 13.10.1962. Leg. R.W. George, FRV 'Dorothea' Cruise 1962 (WAM S56792, ex 928-66, 1 s.v.); **North West Shelf**, 40 miles W. of Cape Jaubert, 18°56'S, 120°55'E, dredged, sponge bottom, 40 m, 13.10.1962. Leg. R.W. George, FRV 'Dorothea' Cruise 1962 (WAM S56791, ex 927-66, 1 s.v.); 60 miles N.W. of Bedout Island, 18°56'S, 118°28'E, dredged, 50 m, 12.10.1962. Leg. R.W. George, FRV 'Dorothea' Cruise 1962 (WAM S56793, ex 922-66, 2 s.v.); 51 nautical miles N. of Port Hedland, 19°29'S, 118°22'E, triangular dredge, 56 m, 01.04.1982. Leg. L.M. Marsh, CSIRO FRV 'Soela' Cruise II 1982, Stn SO2/82/12A (WAM S84466, 5 s.v.); 72 miles N.W. of Bedout Island, 19°01'S, 118°09'E, dredged, 50 m, 12.10.1962. Leg. R.W. George, FRV 'Dorothea' Cruise 1962 (WAM S56794, ex 932-66, 1 s.v.); 57 nautical miles N.W. of Port Hedland, 19°34.2'S, 117°57.4'E, trawl, sand, shell and rubble, 60–65 m, 05.10.1982. Leg. L.M. Marsh & M. Bezant, CSIRO FRV 'Soela' Cruise V 1982, Stn S05/82/063 (WAM S84467, 2 s.v.); 67 nautical miles N.N.E. of Cape Lambert, 19°31.4'S, 117°26.0'E, sled, sand, flat sponges, gorg, long hydroids, 78 m, 17.08.1995. Leg. L.M. Marsh, AIMS Survey RV 'Lady Basten'1995, Stn AIMS/95/LB3 (WAM S84461, 1 s.v.); 38 nautical miles N. of Port Walcott, 19°59'S, 117°16'E, triangle dredge, silty sand and bryozoa, 50–52 m, 15.04.1982. Leg. L.M. Marsh, CSIRO FRV 'Soela' Cruise II 1982, Stn SO2/82/54A (WAM S84460, 5 s.v.); Dampier Archipelago, 11 nautical miles N.N.E. of Legendre Island, 20°12.7'S, 116°55.3'E, trawl, 43 m, 17.08.1995. Leg. L.M. Marsh, AIMS Survey RV 'Lady Basten'1995, Stn AIMS/95/LB1 (WAM S84462, 4 s.v.); N. of Malus Island, 19°45'S, 116°38'E, otter trawl, 57–60 m, 04.12.1979. Leg. L.M. Marsh & S.M. Slack-Smith, CSIRO FRV 'Soela' Cruise I 1979, Stn SO1/79/0028 (WAM S84459, 2 s.v., 1 fragm.); **Pilbara Nearshore/ Offshore**, Dampier Archipelago, N. of N.W. point of Eaglehawk Island, 20°38.94'S, 116°26.22'E, dive, very low rock ridges & silty sand, 10 m, 03.09.1999. Leg. S.M. Slack-Smith et al., Woodside Dampier Exped. III 1999, Stn DA3/99/56 (WAM S84463, 1 s.v.); N.W. of Rosemary Island, 20°03'S, 116°10'E, otter trawl, 62–65 m, 04.12.1979. Leg. L.M. Marsh & S.M. Slack-Smith, CSIRO FRV 'Soela' Cruise I 1979, Stn SO1/79/0036 (WAM S84464, 1 s.v.); N.E. of Montebello Islands, 19°54'S, 116°00'E, otter trawl, 76–78 m, 03.12.1979. Leg. L.M. Marsh & S.M. Slack-Smith, CSIRO FRV 'Soela' Cruise I 1979, Stn SO1/79/0022-23 (WAM S84468, 1 s.v.); Montebello Islands, Bunsen Channel, N. end of Trimouille Island, 20°23'08"S, 115°32'43"E, scuba, 21.08.1993. Leg. C. Bryce & S.M. Slack-Smith, WAM Montebello Islands Survey 1993, Stn MB/93/28a

(WAM S84457, 1 s.v.); **Ningaloo**, Ningaloo Marine Park, Torpedo Bay, 21°49.876'S, 113°58.407'E, epibenthic sled, 50.69–56.78 m, 05.05.2007. Leg. M.P. Salotti, AIMS-WAM RV 'Cape Ferguson' Ningaloo Survey II May 2007, Stn CF4314/2007/D059 (WAM S84455, 1 s.v.); **Undefined bioregion:** 'Dampier, Beagle Bay' [sic], taken during low tide from six feet of water, close to shoreline in beach area, sand and seagrass with rocks bottom, 03.1979 (S. Hobbs, U.S.A., 2 p.v.); WA, before 1980, ex coll. A.P.W. Herlaar (TP 4188, 1 p.v.); WA, 1979 (H. van Rij, The Netherlands, no reg. no., 2 p.v.).

Unknown provenance: ex coll. J. Drijver (TP 4174, 2 p.v.; E. Kaptein, The Netherlands, 1104.5, 3 p.v.).

DESCRIPTION

Shell rather large for the genus (H up to 61.3 mm) and solid, elongately ovate, inaequilateral, strongly elongate (H/L 1.63–1.95, n = 16, H 40.8–61.3 mm, Figure 14) and highly attenuate towards the umbos, moderately inflated. Anterior and ventral margins regular rounded, posterior margin slightly convex with straight median part, postero-ventral margin angular rounded, antero-dorsal marginal area bending towards the inside of the shell. Lunule well marked and strongly excavated at shell margins, valves beneath lunule slightly gaping; escutcheon hardly defined. Exterior glossy and almost smooth, very weakly radially ribbed on central part of shell disc, almost of a subsurface nature, crossed by minute commarginal growth lines; anteriorly well demarcated commarginally slightly undulating close-set riblets; posteriorly irregular, well spaced commarginally slightly undulating riblets, most expressed towards the posterior margin and largely replaced by weak radial riblets in the juvenile stage. Two well defined radial ribs present near postero-dorsal margin, carrying weakly demarcated nodules when crossed by commarginal riblets. Mean number or radial ribs 56.5 (range 51–59, n = 8), rib count based on internal marginal ribbing. Margins crenulated, rib impressions not extending far into the shell. Hinge typical for the genus, almost symmetrical and strongly arched, angle A (formed by r.v. ventral lateral teeth and dorsal end of cardinals) approximately 75–80°, cardinal socket very narrow and deep. Exterior colour dirty white to pale yellow with variable red-brown zig-zag and chevron patterns, composed of segments that are confluent with the indistinct radial ribs, less numerous but darker on posterior slope; interior white, except for light orange-yellow umbonal cavity, sometimes consisting of two broad radial bands, external coloration vaguely visible internally. Periostracum thin, light olive-green.

DISTRIBUTION AND ECOLOGY

In northern WA, this new species appears to be restricted to the inner and mid-continental shelf, and has been found most frequently off the Pilbara Coast (Figure 20B). It is appears to be a Dampierian endemic, ranging from Ningaloo to the Torres Strait. The ANSP 219279 Darwin record is considered untrustworthy (personal communication P. Callomon, 2015) as is the QLD sample in the collection of S. Hobbs (dealer specimens). Depth range 2–78 m, based on dead recordings; 20 m, live record.

REMARKS

Vidal (1999) reviewed the related species *Acrosterigma attenuatum* (G.B. Sowerby II, 1841). His assignment in *Acrosterigma*, based on morphology, has been confirmed by molecular analysis (Herrera et al. 2015) and is adopted for *A. extremattenuatum* sp. nov. *Acrosterigma attenuatum* (Figures 13I–N, 14) differs by being less elongate and attenuate (H/L 1.40–1.61, n = 25, H 43.0–65.9 mm), by being more inflated, by a yellow-orange colour that is generally lacking the prominent red-brown zigzag configuration (if present, confined to the posterior slope), by a less stronger arched hinge (angle A approximately 80–90°), by a less hollowed antero-dorsal marginal area, by a less pronounced commarginal ribbing on the anterior slope and by a larger maximum size (largest observed specimen: H 86.7 mm from Sri Lanka, RMNH, ex ZMA). Whereas a weak sterigma is present in the umbonal cavity of 40% of the investigated samples of *A. attenuatum* (Vidal 1999), this seems to be lacking in *A. extremattenuatum* sp. nov.

Only one *A. attenuatum* sample (Aru, Indonesia, WAM S67690; Figure 13I) was observed with a similar colour pattern as *A. extremattenuatum* sp. nov. However, it differs in being less elongate, by a less strongly arched hinge and by the absence of an inward curving, antero-dorsal marginal area.

ETYMOLOGY

The specific epithet refers to the extremely elongate and dorsally attenuate shape of the shell, more than any other of its congeners (Vidal 1999: Table 2), including *A. attenuatum* (G.B. Sowerby II, 1841).

Acrosterigma punctolineatum Healy & Lamprell, 1992

Figures 12K–N, 20C

Acrosterigma sp. — Lamprell and Whitehead 1992: pl. 30 fig. 199 [= QM MO32905 holotype of *A. punctolineatum*].

Acrosterigma punctolineata Healy & Lamprell, 1992: 87–89, pl. 3e–h.

Acrosterigma punctolineata Healy & Lamprell, 1992 — Lamprell and Healy 1998: 256.

Acrosterigma punctolineatum Healy & Lamprell, 1992 — ter Poorten 2009: pl. 1 fig. 12; Huber 2010: 297, fig.; ter Poorten 2011: pl. 1088 fig. 3.

MATERIAL EXAMINED

Australia: ***Northern Territory:*** **Cobourg**, Orontes Reef, off Port Essington, 11°16'S, 132°09'E, 9–12 m, 10.08.1986. Leg. S.M. Slack-Smith, WAM Northern Territory Survey Aug. 1986, stn NTS/86/CP#93 (WAM S9906, ex 42-95, 1 s.v.); Orontes Reef, Port Essington, 11°04'S, 132°05'E, 11–14 m, 13.08.1986. Leg. S.M. Slack-Smith, stn SS/CP103 (WAM S79383, 1 s.v.); **Oceanic Shoals**, N.W. of Bathurst Isl., Parry Shoals, 11°12.5'S, 129°42.3'E, 16–18 m, 01.11.2016. Leg. H. Morrison (TP 4678, 1 p.v.).

Australia: ***Western Australia:*** Kimberley, S. end of Long Reef, 14°01'S, 125°44'E, 18.07.1988. Leg. F. Wells & C. Bryce, WAM Kimberley Islands Survey 1988, Stn 650 (WAM S56960, 1 s.v.); Yankawingarri Island, 14°09'S, 125°39'E, 4–14 m, 19.08.1991. Leg. F. Wells & C. Bryce, WAM Kimberley Islands & Reefs Survey 1991, Stn 20 (WAM S56950, 1 s.v.); Cassini Island, 13°57'03.961"S, 125°38'54.238"E, 12 m, 14.10.2010. Leg. C. Bryce & C. Whisson, Woodside Kimberley Survey 2010, Stn 29/K10 (WAM, S58854, 1 p.v., 1 s.v.); Cassini Island, 13°56'S, 125°38'E, 09.1998. Leg. H. Morrison & C. Bryce, WAM Offshore Kimberley Survey 1998 (WAM S57116, 1 p.v.); Solem Islands, 14°11'S, 125°38'E, 4–18 m, 19.08.1991. Leg. F. Wells & C. Bryce, WAM Kimberley Islands & Reefs Survey 1991, Stn 22 (WAM S56951, 1 p.v.); Institut Islands, S.E. end of Condillac Island, 14°06'S, 125°33'E, 15 m, 18.08.1991. Leg. F. Wells & C. Bryce, WAM Kimberley Islands & Reefs Survey 1991, Stn 18 (WAM S56949, 1 s.v.); East Montalivet Island, 14°16'38"S, 125°18'13"E, 15.07.1988. Leg. F. Wells & C. Bryce, WAM Kimberley Islands Survey 1988, Stn 50 (WAM S56598, 1 s.v.); **North West Shelf**, S.E. Mermaid Reef, 17°46'6.23"S, 120°43'9.12"E to 17°45'56.87"S, 120°42'56.51"E, 97–109 m, 20.06.2007. Leg. C. Whisson & O. Gomez, CSIRO RV 'Southern Surveyor' Cruise, Stn SS0507/097 (WAM S32858, 1 s.v.).

DESCRIPTION

Shell small to medium (H 30–46 mm), rather thin, equilateral to posteriorly expanded, ovoid and moderately elongate. Between 42–55 rounded radial ribs with numerous transverse ridges, more prominent anteriorly and posteriorly replaced by oblique scales. Interstices small and finely striated. Lunule small and elongated. External coloration white with very characteristic broken light brown lines and subsurface green-brown spots, located on the surface and nearly black on the posterior quarter. Interior reflects exterior colouration but is more prominent.

DISTRIBUTION AND ECOLOGY

The distribution of *A. punctolineatum* is now well established in the Central IWP (Vidal 1999; ter Poorten 2009), but until this study, it was not known from outside of QLD and NT in Australia (Vidal 1999). In WA, it has been recorded predominantly from nearshore communities in the Kimberley, consistent with other records for this species from shallow water, reefal environments (Figure 20C).

REMARKS

The largest specimen observed sofar is from QLD (NTM P.31486, H 46.2 mm). Three possible syntypes of *Cardium foveolatum* G.B. Sowerby II, 1840 (NHMUK 1996514, the largest figured by Reeve 1845: pl. 18 fig. 87 based on a figure produced by G.B. Sowerby II; Fig. 1M) are fully in agreement with the present species. However, type figure, dimensions and Swan River type locality (G.B. Sowerby II 1840a: fig. 65; 1840b: 3; 1841: 111/511) are more in agreement with *Cardium cygnorum* Deshayes, 1855, as discussed by Wilson and Stevenson (1977). Hence, the true identity of Sowerby's *C. foveolatum* remains unresolved. *Acrosterigma punctolineatum* is sister to *A. hobbsae* Vidal, 1999, a species that is also known from QLD (NTM P.54171), as well as from the southern Indonesian islands of Sumbawa and Timor (TP 1337, 1338).

Acrosterigma simplex **(Spengler, 1799)**

Figures 12U–X, 20D

Cardium simplex Spengler, 1799: 31.

Cardium unicolor G.B. Sowerby II, 1834: fig. 29; 1840a: fig. 42; 1840b: 4, sp. 46.

Cardium nebulosum Reeve, 1845: sp. 99, pl. 19 fig. 99.

Laevicardium soyeri Fischer-Piette, 1977: 19–20, pl. 1 figs 4–7.

Acrosterigma unicolor (Sowerby, 1834) — Lamprell and Whitehead 1992: pl. 30 fig. 197.

Acrosterigma simplex (Spengler, 1799) — ter Poorten 2009: pl. 2 figs 1–3, pl. 5 fig. 3; Huber 2010: 297, fig.; ter Poorten 2011: pl. 1089 figs 6–7.

MATERIAL EXAMINED

Australia: ***Western Australia:*** **Oceanic Shoals**, N. side of Cartier Island, 12°31.5'S, 123°33.5'E, in sand and bommies, 20–30 m, 09.1998. Leg. H. Morrison (TP 1339, 1 p.v.); **Canning**, Broome, Quong Dong, in muddy sand

under stones, high intertidal, alive, 10.2009. Leg. W. Van Damme (TP 3988, 1 p.v.); **Pilbara Offshore**, Montebello Islands, Hermite Island, S. end of Stephenson Channel, 20°29'59"S, 115°31'50"E, 4 m, 15.08.1993. Leg. S.M. Slack-Smith, WAM Montebello Islands Survey 1993, Stn MBI/93/16 (WAM S78358, 1 p.v.).

DESCRIPTION

Shell medium (H 30–53 mm; only 4.2 mm in the present WAM material), rather solid, subequilateral, variably elongated, posteriorly slightly expanded and inflated. Margins rounded, central area of posterior margin in adults straight. Between 40–59 rather flattened radial ribs, rib sculpture anteriorly crenate laterally, posteriorly poorly ornamented. Interstices small, showing fine growth striae. Lunule large and asymmetric, larger on right valve. Periostracum relatively well developed on posterior slope. Exterior colour uniform light greyish-cream or yellowish, often darkened posteriorly, interior white, sometimes with splashes of pink or purple (ter Poorten 2009).

DISTRIBUTION AND ECOLOGY

This common shallow water species has a large but patchy distribution in the IWP (distribution map: Vidal 1999: fig. 18) and is known from neighboring countries and states including Indonesia (ter Poorten 2007), also West Timor, Roti Island (ZMA, Siboga Exped.) and QLD. The present samples are the first records of *A. simplex* from WA (Figure 20D).

REMARKS

The sole WAM record of this species is a juvenile specimen (Figures 12U–X, H 4.2 mm). *Acrosterigma simplex* is distinguishable from other congeners by its rounded outline in the juvenile stage, its wide lunule (larger in r.v.), the lack of bright colours and by the ontogenetic disappearance of scales on the posterior quarter (Vidal 1999; ter Poorten 2009).

Acrosterigma suduirauti Vidal & ter Poorten, 2007

Figures 12O–R

Acrosterigma suduirauti Vidal & ter Poorten, 2007: 72–74, figs 1–6, 11.

Acrosterigma suduirauti Vidal & ter Poorten, 2007 — ter Poorten 2011: pl. 1090, figs 2–6.

MATERIAL EXAMINED

Australia: ***Western Australia:*** **Oceanic Shoals**, Rowley Shoals, Imperieuse Reef L23 east, 17.5951°S, 118.9817°E to 17.5891°S, 118.9799°E, 108–140 m, 16.06.2007. Leg. C. Whisson, CSIRO RV 'Southern Surveyor' Cruise, Stn SS0507/062 (WAM S32883, 6 s.v.).

DESCRIPTION

Shell medium sized (H up to 38 mm), rather thin-shelled, slightly elongate-quadrate, inflated. Margins rounded, posterior margin nearly straight. Between 51–65 rounded radial ribs, becoming more oblique triangular posteriorly and separated by narrow interstices. Anterior ribs carrying commarginal scales covering complete rib width, median ribs carrying straight ridges on their posterior side and posterior ribs with well developed, distantly placed oblique ridges. Hinge typical for the genus, lunule small with raised margins. Exterior coloration whitish, yellowish, or orange with irregular red-brownish stains. Interior colours reflects exterior by transparency.

DISTRIBUTION AND ECOLOGY

Records of this species are previously thought to be restricted to the Philippines and Indonesia. The present record from WA not only implies a southward range extension but is the first record of this species in Australia. The sole WA record originates from the Rowley Shoals, situated on the outer edge of the continental shelf (Figure 1).

REMARKS

The Australian valves are in full agreement with the type material. It belongs to a group of deep water *Acrosterigma* species/specialists, although this notion is exclusively based on dead recordings of mostly single valves. Its closest congener is *A. profundum* Vidal, 1999, which also occurs in deep water but is mainly recorded from New Caledonia, Fiji and the Marshall Islands (colln MNHN, det. TP).

Acrosterigma variegatum (G.B. Sowerby II, 1840)

Figures 12S–T, 20E

Cardium variegatum G.B. Sowerby II, 1840a: fig. 57; 1840b: 4, sp. 45; 1841: 107.

Acrosterigma variegatum (G.B. Sowerby II, 1840) — Huber 2010: 297, fig.; ter Poorten 2011: pl. 1089, figs 8–9.

Vasticardium swanae Maxwell, Congdon & Rymer, 2016: 249, fig. 1, 2G, back cover (syn. nov.).

MATERIAL EXAMINED

Australia: ***Western Australia:*** **Oceanic Shoals**, Ashmore Reef, Lagoon middle entrance, 12°11'40.128"S, 123°03'00.533"E, scuba, 7.4 m, 01.10.2013. Leg. Kirkendale, L. & Bryce, C., Woodside Kimberley Survey 2013, Stn 136/K13 (WAM S75358, 2 s.v.); **Pilbara Offshore**, Exmouth, dived, in sand, 20–

FIGURE 15 A,B, *Vasticardium elongatum* (Bruguière, 1789). Ashmore Reef, WA: WAM S56890, height 68.8 mm. A, exterior of l.v., B, interior of l.v.

C, D, E, F, G, *Vasticardium mindanense* (Reeve, 1844). C–E, Ashmore Reef, WA: NTM P.10066, height 29.3 mm; C, exterior of l.v., D, interior of l.v., E, posterior slope of l.v.; F–G, Cagayan, Philippines: NHMUK 1978124, lectotype, height 40.4 mm. F, exterior of l.v., G, interior of l.v.

H, I, J, *Vasticardium philippinense* (Hedley, 1899). Broome, WA [probably originating from northern offshore reefs]: TP 2046, height 76.2 mm. H, exterior of l.v., I, interior of r.v., J, posterior.

25 m. Leg. Gary Wilson (TP 2264, 1 p.v.); **Ningaloo**, Ningaloo Marine Park, 22°46'15"S, 113°38'4"E to 22°46'14"S, 113°38'3"E, 55 m, 08.02.2008. Leg. S.M. Slack-Smith, AIMS RV 'Solander' Cruise, Stn RVS4545-D116 (WAM S43505, 1 s.v.).

Literature records: Torres Strait, off Murray Isl., 9°54'34"S, 144°02'37"E (Vidal, 1999: AMS C.30279).

DESCRIPTION

Shell rather large (H up to 60 mm), relatively solid, ovate and moderately inflated. Margins rounded, posterior margin nearly straight. Between 36–45 rounded radial ribs, becoming more pointed triangular on median-posterior part and separated by rather narrow interstices. Anterior ribs carrying close-set commarginal scales, median ribs hardly sculptured and posterior ribs flattened with erect, oblique ridges on their posterior side. Hinge typical for the genus, lunule small on left valve, much wider and deeply excavated on right valve. Exterior coloration whitish with irregular orange or red-brownish patches; interior white, with exterior colours more or less visible, margin yellowish to a variable degree or white.

DISTRIBUTION AND ECOLOGY

Australian distributional records are from northern QLD: Murray Island (E. of Torres Strait entrance), Port Douglas and Kurrimine (Vidal 1999; TP 4198). The two WAM records are from offshore coral reef settings (Ashmore Reef in the far north and Ningaloo) (Figure 20E). *Acrosterigma variegatum* is known from shallow water with sandy bottoms in coral reef environments and given the abundance of this habitat in WA, is expected to be widely distributed offshore.

REMARKS

The specimens from WA are both remarkably large (H 56.6; 60.0 mm), one exceeding the maximum height (58.1 mm) as given by Vidal (1999) — apparently resulting from favourable environmental factors. However, other characters are entirely consistent with the known morphology of the species, including the typical nature of the lunule.

Recently *Vasticardium swanae* Maxwell, Congwon & Rymer, 2016 has been introduced, apparently based on a single specimen from Bramble Reef, QLD. It differs from *A. variegatum*, by 'having a curved margin and shell which is distinctly more ovate' and by lacking the tinged yellow internal margin (Maxwell et al. 2016: 250). However, the shell shape of *A. variegatum* agrees with *V. swanae*. This is apparent when one compares the syntypes of the former species (NHMUK 20140803, Hylleberg 2004: 870, unnumbered figures) with a figure of the holotype of *V. swanae* placed on the back cover of the journal in which the species has been described (not photographed under an angle, unlike the figure accompanying the description; high resolution version kindly made available by the editor of the journal, David Berschauer). The yellow internal margin is variably developed in *A. variegatum* and therefore unreliable for taxonomic separation; it is hardly present in the syntypes. As the rib number ('40–50', not given for the holotype of *V. swanae*, c. 42 ribs can be counted), rib sculpture, rib shape and external coloration all match, there is no reason to separate the QLD population and *V. swanae* is herein regarded a synonym of *A. variegatum*.

Genus *Vasticardium* Iredale, 1927

Vasticardium Iredale, 1927: 75–76. Type species by original designation: *Cochlea nebulosa* Martyn, 1784 [= *Cardium elongatum* Bruguière, 1789]; Recent (type locality not mentioned).

Regozara Iredale, 1936: 275. Type species by original designation: *Regozara olivifer* Iredale, 1936 [= *Cardium vertebratum* Jonas, 1844]; Recent, Sydney Harbour, New South Wales, Australia.

Vasticardium elongatum (Bruguière, 1789)

Figures 15A–B

Cochlea nebulosa Martyn, 1784: 50, pl. 46 fig. 1 (rejected work).

Cardium elongatum Bruguière, 1789: 228–229.

Vasticardium elongatum (Bruguière, 1789) — Huber 2010: 293, fig. [*pars*]; ter Poorten 2011: pl. 1092 figs 4–6.

Not: *Acrosterigma elongatum* (Bruguière, 1789) — Wilson and Stevenson 1977: 78–80, pl. 5 figs 1–4 [= paratype of *Acrosterigma wilsoni* Voskuil & Onverwagt, 1991, WAM S65194).

Not: *Acrosterigma elongata* (Bruguière, 1789) — Lamprell and Whitehead 1992: pl. 29 fig. 186 [= *Vasticardium coralense* (Vidal, 1993)].

MATERIAL EXAMINED

Australia: ***Western Australia:*** **Oceanic Shoals**, Ashmore Reef, Lagoon middle entrance, 12°11'40.128"S, 123°03'00.533"E, scuba, 7.4 m, 01.10.2013. Leg. L. Kirkendale & C. Bryce, Woodside Kimberley Survey 2013, Stn 136/K13 (WAM S75817, 1 s.v.); West Island,

12°11'S, 122°58'E, 16.10.1978. Leg. B.R. Wilson, Bogorov 1978 Exped. (WAM S56890, 1 p.v. of which 1 valve fragm.); Ashmore Reef, 25.09.1988/1989. Leg. M. Claydon (TP 4827, 1 p.v.).

DESCRIPTION

Shell large (H 100–135 mm), solid, almost equilateral, elongate and inflated. Margins rounded, posterior margin often almost straight. Anterior margin crenulate, ventral and posterior margin digitate. Between 35–44 radial ribs, flat-topped, square-sided on anterior and median part and low rounded with radial cord on top on posterior part. Ribs marginally serrated on anterior and median part, posterior 3–5 ribs with small oblique scales. Interstices narrow and smooth. Lunule well defined and weakly raised dorsally. Exterior cream with various shades of brown-yellow to purple, especially on postero-ventral slope; internally white with yellowish brown anterior margin and purple or pink ventral and posterior margin.

DISTRIBUTION AND ECOLOGY

In WA, true *V. elongatum* appears confined to the northern offshore reefs, based on two shallow water records from Ashmore Reef. It is found in the Central IWP in the Philippines and central Indonesia.

REMARKS

Vidal (1993) established six geographic subspecies of the polytypic *Cardium elongatum* Bruguière, 1789, drawing on the observation that many transitional specimens occur in each geographic region and following the 75 per cent rule of Mayr et al. (1953). Initially these were assigned to *Acrosterigma*; later Vidal (1996) transferred them to *Vasticardium*. Two of these taxa occur in WA, *Vasticardium elongatum* (Bruguière, 1789) and *V. wilsoni* (Voskuil & Onverwagt, 1991); the former is distributed in the hyperdiverse Philippines-Indonesia region, the latter is restricted to northern Australia. A long-term study of this species complex by the first author made clear that all these taxa show allopatric distribution patterns, that the number of transitional specimens is very limited and that distribution boundaries coincide with geographic barriers in dispersal. Co-occurrences are lacking, even in the Indonesia-Philippines region. Altogether, these criteria are strongly indicative of allopatric speciation, hence all taxa in the *elongatum* complex are herein given specific status.

The samples attributed by Wilson and Stevenson (1977) to this species invariably proved to represent *V. wilsoni*. In contrast to the strictly inshore and continental shelf distribution of this species, the oceanic records of *V. elongatum* are proof of connectivity with the Central IWP region. The three WA samples represent the first Australian records of *V. elongatum*. Two of these (WAM S56890, Figures 15A–B, arrow; TP 4827) are tuberculated forms (small rounded tubercles present on the posterior slope).

Vasticardium mindanense (Reeve, 1844)

Figures 15C–G

Cardium mindanense Reeve, 1844: sp. 19, pl. 4 fig. 19.

Vasticardium lomboke Vidal, 2003: 58, figs 4–5, 8 (syn. nov.).

MATERIAL EXAMINED

Australia: ***Western Australia:*** **Oceanic Shoals**, Approx. mid-northern coast of Ashmore Reef, 12°13.47'S, 122°57.77'E, 24 m, on the surface of silty sand at the base of outer reef slope, 06.09.1996. Leg. R.C. Willan (NTM P.10066, 1 s.v.).

DESCRIPTION

Shell medium sized (H 40–50 mm), solid, almost equilateral, slightly elongate and inflated. Margins rounded, posterior margin straight. Anterior margin crenulate, ventral and posterior margin digitate. Between 33–38 prominent radial ribs, oblique-square-sided on anterior and median part and triangular to trapezoidal on posterior part. Ribs carrying crescent-shape rugae on anterior part, becoming V-shaped on median part and oblique scales along with fine ridges on rib sides on posterior part (Figure 15E). Interstices about one third of the rib width. Lunule narrow, slightly wider in right valve. Exterior white with purple-brown more or less commarginally arranged maculations; internally white with umbonal cavity sometimes purple.

DISTRIBUTION AND ECOLOGY

Only one sample was recovered from WA (the first Australian record) and it was collected from Ashmore Reef, one of the emergent reefs of the northernmost Sahul Shelf (Figures 15C–E). It is widely distributed in the Central IWP, mostly found in shallow water and nearly always taken from death assemblages, suggesting that its preferred habitat has not been sampled.

REMARKS

Vasticardium mindanense is a typical component of the Central IWP molluscan fauna that has colonised the northern offshore reefs, with larval dispersal enhanced by the main oceanic current system, the ITF (Willan 2005; Wilson 2013). The lectotype of *Cardium mindanense* (NHMUK 1978124, Figures 15F–G) has been compared with the holotype of *Vasticardium lomboke* Vidal, 2003 (MNHN-IM-2000-3998),

originating from the N.W. coast of Lombok, Indonesia. Although the shell is worn, polished and juvenile (H 29.3 mm), close examination leads to the conclusion that both are identical and that *V. lomboke* should be regarded as a junior synonym. The *V. mindanense* group has recently been revised (Hylleberg, 2017).

Vasticardium philippinense (Hedley, 1899)

Figures 15H–J, 20F

Cardium angulatum Lamarck: Reeve, 1845: sp. 70, pl. 14 fig. 70 (non *Cardium angulatum* Lamarck, 1819).

Cardium philippinense Deshayes: Hedley, 1899: 503–504.

Cardium (*Trachycardium*) *pseudoangulatum* Bülow, 1905: 79–80, pl. 1 fig. 3.

Acrosterigma mendanaense (Sowerby, 1896) — Lamprell and Whitehead 1992: pl. 29 fig. 188 [Not *Vasticardium mendanaense* (G.B. Sowerby III, 1897)].

'*Acrosterigma obesa* (Broderip & Sowerby, 1833)' [*nomen nudum*] — Lamprell and Healy 1998: 256.

Vasticardium philippinense (Hedley, 1899) — ter Poorten 2009: pl. 3 figs 4–5; Huber 2010: 296, fig.; ter Poorten 2011: pl. 1093 figs 4–5.

MATERIAL EXAMINED

Australia: ***Northern Territory:*** **Oceanic Shoals**, 155 km due N. of central northern coast of Melville Island, Lynedoch Bank, 10°1'S, 130°48'E, 03.12.2014. Leg. H. Morrison (NTM P.54750, 1 p.v.); 230 km N.W. of northern coast of Bathurst Island, central Arafura Sea, Flinders Shoals, 9°43'11"S, 129°48'0"E, 13–15 m. 03.11.2015. Leg. H. Morrison (NTM P.55751, 2 p.v.).

Australia: ***Western Australia:*** **Oceanic Shoals**, 240 km N.W. of northern coast of Bathurst Island, central Arafura Sea, Martin Shoal, 9°36.64'S, 128°52.6'E, 16–20 m. 03.11.2015. Leg. H. Morrison (NTM P.55827, 1 p.v., A; NTM P.55829, 1 p.v.); 260 km N.W. of northern coast of Bathurst Island, central Arafura Sea, Loxton Shoal, 9°36'18"S, 128°43'12"E, 17–18 m. 03.11.2015. Leg. H. Morrison (NTM P.56004, 4 p.v., A); Vulcan Shoal, 12°47'57.481"S, 124°16'00.205"E, 19 m, 06.10.2013. Leg. L. Kirkendale & C. Bryce, Woodside Kimberley Survey 2013, Stn 146/K13 (WAM S91778, 1 s.v.); Heywood Shoal, 12°26'50.675"S, 124°01'56.785"E, 24 m, 07.10.2013. Leg. L. Kirkendale & C. Bryce, Woodside Kimberley Survey 2013, Stn 148/K13 (WAM S91794, 2 s.v.); Echuca Shoals, 13°53'46.86"S, 123°53'41.136"E, 21 m, isolated outcrop, 18.10.2012. Leg. C. Bryce, Woodside Kimberley Survey 2012, Stn 107/K12 (WAM S85182, 1 p.v.); Echuca Shoals, 13°54'02.484"S, 123°53'36.412"E, 19 m, isolated outcrop, 18.10.2012. Leg. C. Bryce, Woodside Kimberley Survey 2012, Stn 108/K12 (WAM S85112, 1 p.v., 1 s.v.); Cartier Island, 12°32'S, 123°33'E, 30 m, sand at base of bommie, 14.09.1998. Leg. C. Bryce, WAM Offshore Kimberley Survey 1998 (WAM S76772, 1 p.v., A); W. end, 12°32.200'S, 123°31.9'E, 17–18 m, on patch of clean sand, 04.05.1992. Leg. R.C. Willan (NTM P.29354, 1 p.v.); Browse Island, 14°06'45.289"S, 123°32'04.475"E, 13 m, fore reef (outer), 16.10.2012. Leg. C. Bryce, Woodside Kimberley Survey 2012, Stn 102/K12 (WAM S85070, 1 p.v.); Hibernia Reef, N.W. corner, 11°55'S, 123°28'E, 24 m, 19.09.1994. Leg. C. Bryce & H. Morrison, Bryce & Morrison Kimberley Survey 1994 (WAM S57109, 2 p.v.); S. side, 11°55'S, 123°28'E, 3 m, 18.09.1996. Leg. H. Morrison & C. Bryce, WAM Offshore Kimberley Survey 1996 (WAM S57110, 1 p.v.); S. side, 11°55'S, 123°28'E, 3 m, sand and coral, 19.09.1996. Leg. H. Morrison & C. Bryce, WAM Offshore Kimberley Survey 1996 (WAM S57111, 1 p.v.); S. side, 11°55'S, 123°28'E, 2 m, 19.09.1996. Leg. H. Morrison & C. Bryce, WAM Offshore Kimberley Survey 1996 (WAM S57112, 1 p.v.); S.E. corner, 11°58'33.781"S, 123°23'22.817"E, 17 m, fore reef (slope), 05.10.2013. Leg. L. Kirkendale & C. Bryce, Woodside Kimberley Survey 2013, Stn 145/K13 (WAM S91819, 1 p.v., 1 s.v.); N.E. side, 11°57'42.012"S, 123°22'42.881"E, 13 m, fore reef (outer), 04.10.2013. Leg. L. Kirkendale & C. Bryce, Woodside Kimberley Survey 2013, Stn 143/K13 (WAM S75883, 1 s.v.); N. side, reef slope, immediately outside entrance to lagoon, 11°57.8'S, 123°22.3'E, 8–12 m, in rubble patches on the floor of surge channels, 10.05.1992. Leg. R.C. Willan (NTM P.13186, 1 p.v., 1 s.v.); S.E. side, 11°59.02'S, 123°22.09'E, 35 m, on surface coral sand, on steep outer reef slope, 13.05.1992. Leg. R.C. Willan (NTM P.35129, 2 p.v.); N. side, base of outer reef slope, just west of 'false entrance', 11°58.01'S, 123°21.02'E, 27 m, on surface of fine coral substrate, '*Halimeda* meadow', 12.05.1992. Leg. R.C. Willan (NTM P.13088, 8 s.v.); S. side, 11°59'17.339"S, 123°20'09.073"E, 24 m, fore reef (slope), 04.10.2013. Leg. L. Kirkendale & C. Bryce, Woodside Kimberley Survey 2013, Stn 142/K13 (WAM S75895, 5 p.v.); W. point, 11°58'26.544"S, 123°19'19.497"E, 15 m, fore reef (slope), 05.10.2013. Leg. L. Kirkendale & C. Bryce, Woodside Kimberley Survey 2013, Stn 144/K13 (WAM S75891, 1 p.v.); 11°58'S, 123°19'E, 09.1998. Leg. H. Morrison & C. Bryce, WAM Offshore Kimberley Survey 1998 (WAM S57113, 6 p.v.); Ashmore Reef, N.E. corner, 12°14'14.208"S, 123°09'36.151"E, 15 m, fore reef (outer), 27.09.2013. Leg. L. Kirkendale & C. Bryce, Woodside Kimberley Survey 2013, Stn 127/K13 (WAM S75140, 3 p.v.); S. side, 12°17'36.6"S, 123°07'25.441"E, 12 m, fore reef (outer), 28.09.2013. Leg. L. Kirkendale & C. Bryce, Woodside Kimberley Survey 2013, Stn 128/K13 (WAM S75818, 1 s.v.); Middle Passage, W., 12°14'S, 123°05'E, 8–20 m, 17.09.1986. Leg. F.E. Wells & C.W. Bryce, WAM Ashmore Reef & Cartier Island Survey 1986, Stn 15 (WAM S78227, ex 43-95, 1 p.v.); approx. mid-northern coast, 12°17'S, 123°02'E, 12 m, amongst coral rubble and coarse sand, outer reef slope, 09.09.1996. Leg. R.C. Willan (NTM P.9204, 2 s.v.); N. Ashmore Reef, 12°11'37.608"S,

123°01'42.228"E, 12 m, fore reef (slope), 26.09.2013. Leg. L. Kirkendale & C. Bryce, Woodside Kimberley Survey 2013, Stn 125/K13 (WAM S75091, 1 s.v.); N.W. coast, W. side of entrance into W. lagoon, 12°13'S, 123°0'E, 1 m, amongst coral rubble, rubble bank at reef crest, 03.09.1996. Leg. R.C. Willan & K.A. Glenn (NTM P.2155, 1 s.v.); western anchorage, 12°11'S, 122°58'E, 17.10.1978. Leg. B.R. Wilson, Bogarov 1978 (WAM S56849, 1 p.v.); N.E. corner, 12°10'S, 122°58'E, 6–8 m, 14.09.1986. Leg. F. Wells & C. Bryce, WAM Ashmore Reef & Cartier Island Survey 1986, Stn 8 (WAM S56846, 1 p.v.); Ashmore Reef, S.E. corner, 12°10'S, 122°58'E, 12 m, 15.09.1986. Leg. F. Wells & C. Bryce, WAM Ashmore Reef & Cartier Island Survey 1986, Stn 10 (WAM S56847, 3 s.v.); reef flat N. of West Island, 12°14'S, 122°58'E, reef flat, 17.09.1986. Leg. F. Wells & C. Bryce, WAM Ashmore Reef & Cartier Island Survey 1986, Stn 16 (WAM S56848, 1 s.v.); N.E. corner, 12°10'S, 122°58'E, outer reef edge, 17.09.1994. Leg. C. Bryce & H. Morrison, Bryce & Morrison Kimberley Survey 1994 (WAM S56966, 1 s.v.); N.E. corner, 12°10'S, 122°58'E, 15–18 m, 17.09.1994. Leg. C. Bryce & H. Morrison, Bryce & Morrison Kimberley Survey 1994 (WAM S56967, 1 p.v.); Ashmore Reef, approx. mid-northern coast, 12°13.47'S, 122°57.77'E, 24 m, on the surface of silty sand, at the base of outer reef slope, 06.09.1996. Leg. R.C. Willan (NTM P.2056, 1 s.v.); approx. mid-northern coast, 12°13.47'S, 122°57.77'E, 22 m, on the surface of silty sand, at the base of outer reef slope, 10.09.1996. Leg. R.C. Willan (NTM P.2008, 2 s.v.); Seringapatam Reef, lagoon, 13°38'S, 122°05'E, 09.1994. Leg. C. Bryce, Bryce & Morrison Kimberley Survey 1994 (WAM S40371, 1 p.v., A); lagoon, 13°38'S, 122°05'E, 8 m, 16.09.1996. Leg. C. Bryce & H. Morrison, WAM Offshore Kimberley Survey 1998 (WAM S39957, 2 p.v.); Seringapatam Reef, no further data, 13°40'S, 122°05'E, 09.1998. Leg. C. Bryce & H. Morrison, WAM Offshore Kimberley Survey 1998 (WAM S39956, 1 p.v.); S. Scott Reef, 0.5 km S.W. Sandy Island, 14°04'28"S, 121°56'16"E, 8–18 m, 07.09.1984. Leg. F. Wells & C. Bryce, WAM Scott & Seringapatam Reefs Survey 1984, Stn 1 (WAM S39921, 1 p.v.); N. Scott Reef, E. side, 13°55'48"S, 121°55'22"E, 9–18 m, 13.09.1984. Leg. F. Wells & C. Bryce, WAM Scott & Seringapatam Reefs Survey 1984, Stn 15 (WAM S39922, 2 fragm. from 1 p.v.; WAM S40375 1 p.v., A); S. Scott Reef, S. Sandy Island, 13°59'S, 121°46'E, 15–20 m, 09.09.1984. Leg. F. Wells & C. Bryce, WAM Scott & Seringapatam Reefs Survey 1984 (WAM S39925, 2 p.v.); S. Scott Reef, S. Sandy Island, 13°59'S, 121°46'E, 18–20 m, 09.09.1984. Leg. T. Knight, WAM Scott & Seringapatam Reefs Survey 1984 (WAM S39923, 1 p.v); S. Scott Reef, S. end, 13°59'S, 121°46'E, 09.1994. Leg. C. Bryce, Bryce & Morrison Kimberley Survey 1994 (WAM S40374, 1 p.v., A); S. Scott Reef, Sandy Island, 13°59'S, 121°46'E, 10.10.2002. Leg. K. Pendoley (WAM S39962 1 s.v.); S. Scott Reef, West horn, outer slope, 14°07.493'S, 121°42.919'E, 4.5–20 m, 19.09.2006. Leg. C.W. Bryce & C.S. Whisson, WAM NWA Shelf Atolls Survey September 2006, Stn 20 (WAM S31125, 1 p.v.); Scott Reef, coral and rock gutters, amongst rubble, 10–20 m, 10.1984 (TP 4447, 1 p.v.); Rowley Shoals, Mermaid Reef, inner lagoon, E. side, 17°05.374'S, 119°38.948'E, 3.5–10.5 m, coral bombie and surrounds, 12.09.2006. Leg. C.W. Bryce & C.S. Whisson, WAM NWA Shelf Atolls Survey September 2006, Stn 1 (WAM S31002, 1 p.v.); Lagoon, Entrance Channel, 17°03.726'S, 119°38.385'E, 0–18 m, 15.09.2006. Leg. C.W. Bryce & C.S. Whisson, WAM NWA Shelf Atolls Survey September 2006, Stn 10 (WAM S31068, 1 p.v.); Clerke Reef, 17°19'01.095"S, 119°23'01.613"E, 12–18 m, 10.10.2014. Leg. C. Bryce, Woodside Kimberley Survey 2014, Stn 170/K14 (WAM S95436, 1 p.v.); 17°16'47.673"S, 119°22'35.878"E, 15 m, 04.10.2014. Leg. C. Bryce, Woodside Kimberley Survey 2014, Stn 154/K14 (WAM S95436, 3 s.v.); N.E. corner, N. of N. passage, outer reef slope, 17°15'42"S, 119°22'06"E, 10–20 m, 22.07.1982. Leg. WA Museum Party, WAM Rowley Shoals Exped. 1982, Stn 14 (WAM S39924, 2 fragm. from 1 p.v.); N.E. end, reef slope, 17°15'17"S, 119°21'46"E, 20 m, 07.1982. Leg. WA Museum Party, WAM Rowley Shoals Exped. 1982, Stn 6 (WAM S39919, 1 p.v.); 17°16'26"S, 119°21'34"E, 0 m, 22.07.1982. Leg. WA Museum Party, WAM Rowley Shoals Exped. 1982, Stn 15 (WAM S39920, 1 s.v.); N. end, outer reef slope, 17°14'50"S, 119°20'18"E, 10–20 m, 24.07.1982. Leg. WA Museum Party, WAM Rowley Shoals Exped. 1982, Stn 8 (WAM S39918, 1 fragm.); E. reef S. of channels, 17°18'S, 119°20'E, 07.1982. Leg. WA Museum Party, WAM Rowley Shoals Exped. 1982 (WAM S39917, 1 p.v.); Imperieuse Reef, 17°17'34.729"S, 119°22'41.481"E, 12 m, 04.10.2014. Leg. C. Bryce, Woodside Kimberley Survey 2014, Stn 156/K14 (WAM S68126, 1 p.v.); 17°32'09.494"S, 118°58'23.705"E, 15 m, 06.10.2014. Leg. C. Bryce, Woodside Kimberley Survey 2014, Stn 158/K14 (WAM S68174, 1 p.v.).

Literature records: Vidal (1997): Ashmore Reef (WAM S78227, ex 43-95, 1 p.v.); Willan (2005): Ashmore Reef, Cartier Reef and Hiberna Reef.

DESCRIPTION

Shell large (H 80–116 mm), solid, elongate, subequilateral to clearly inequilateral in the adult with slight expansion of posterior slope. Anterior and ventral margin rounded, occasionally straight in fully adult specimens. Between 36–42 oblique squarish to triangular radial ribs, with top or posterior oblique side ridges and erect lamellae on postero-dorsal slope. Hinge with hooked base of the anterior lateral on both valves, hinge plate broad. Lunule large and well delimited with raised margins. External colour white or tan with brownish-purple irregular splashes, more pronounced posteriorly and with dark brown stains towards posterior margin; internally white to yellow with margin bright purple and hinge plate bordering lunule orange-yellow.

DISTRIBUTION AND ECOLOGY

In WA, *V. philippinense* is very common but strictly confined to the oceanic emergent reefs of the shelf margin: out of 55 records, not a single one is known from the continental coast (Figure 20F). This offshore occurrence often coincides with a wide IWP

FIGURE 16 A, B, C, D, *Vasticardium sewelli* (Prashad, 1932). Martin Shoal, WA: TP 4679, height 64.4 mm. A, exterior of l.v., B, interior of r.v., C, posterior, D, dorsal.

E, F, *Vasticardium serricostatum* (Melvill & Standen, 1899). Torres Straits, QLD: NHMUK 1899.2.23.10, syntype, height 21.5 mm. E, exterior of l.v., F, interior of l.v.

G, H, I, *Vasticardium wilsoni* (Voskuil & Onverwagt, 1991). Dampier, WA: TP 2086, paratype, height 73.0 mm. G, exterior of l.v., H, interior of r.v., I, posterior.

distribution. It is restricted to oligotrophic conditions and lives in shallow water in exposed coral reef environments, predominantly on clean sandy bottoms (ter Poorten 2009).

REMARKS

Material under the name '*Acrosterigma orbita* (Broderip & Sowerby, 1833)' recorded from Rowley Shoals and Scott Reef (Wells and Slack-Smith 1986; Bryce and Whisson 2009) and from Ashmore Reef and Cartier Island (Wells 1993) refers to this species. True *Vasticardium orbita* is restricted to the southwest Pacific. While true *V. mendanaense* (name wrongly employed by Lamprell and Whitehead 1992, Willan et al. 2015) is a narrow range endemic occurring off the Marquesas Islands (Vidal 1997). The ecological preferences of *V. philippinense* well describe the ecological category described by Wilson (2013: 272–273): 'The reef species inhabiting the shelf-edge and outer shelf reefs of the Oceanic Shoals Bioregion are predominantly widespread IWP planktotrophic, oceanic species, capable of long-distance dispersal and colonization of remote localities'. The biggest WA specimen has a height of 112 mm (WAM S40371), which nearly equals the largest size known.

Vasticardium sewelli (Prashad, 1932)

Figures 16A–D

Cardium sewelli Prashad, 1932: 268, pl. 6 figs 25–26.

Cardium (*Trachycardium*) *laddi* Abrard, 1946: 33–34, pl. 3 figs 1–2.

Vasticardium sewelli (Prashad, 1932) — ter Poorten 2009: pl. 4 figs 3–4; ter Poorten 2011: pl. 1093 fig. 1.

"Vasticardium" sewelli (B. Prashad, 1932) — Huber 2010: 296, fig.

MATERIAL EXAMINED

Australia: ***Northern Territory:*** **Oceanic Shoals**, N.W. of Bathurst Isl., Parry Shoals, 11°12.5'S, 129°42.3'E, 16–18 m, in sand, rubble and coral, 04.11.2015. Leg. H. Morrison (TP 4731, 1 p.v.).

Australia: ***Western Australia:*** **Oceanic Shoals,** Martin Shoal, 9°36.64'S, 128°52.6'E, 16–50 m, in live coral and rubble, 03.11.2015. Leg. H. Morrison (TP 4679, 1 p.v.).

DESCRIPTION

Shell rather large (H 50–66 mm), solid and elongate, subquadrate, subequilateral and strongly inflated. Juveniles more rounded. Margins gently rounded except for nearly straight posterior margin. Between 36–41 radial ribs. Anterior and medial ribs with pronounced, closely set imbricating scales, rounded on anterior slope, more or less chevron-shaped and slightly transverse on central part. Posterior ribs with raised, transverse imbricating scales, more distantly placed and wearing off easily. Interstices with fine growth striae. Lunule and escutcheon narrow but clearly defined. Hinge plate strong, broad and weakly arched. Exterior coloration ranging from white or yellow to pinkish, mottled with tan-orange or brownish blotches. Lunule and escutcheon may be pink or purple. Interior white with the umbonal cavity occasionally pale cream; margins rarely reddish brown or yellowish brown.

DISTRIBUTION AND ECOLOGY

The present specimen is the first sample recovered from WA and has been collected from Martin Shoal (Figures 16A–D), very close to the border of NT (Figure 1). It is taken from a depth of 16–50 metres, has 38 ribs and with a height of 64.4 mm, is close to the maximum height known (New Caledonia, MNHN-IM-2012-33595, H 66.4 mm). An additional, smaller specimen has recently been taken from Parry Shoals, NT (11°12.5'S, 129°42.3'E; colln TP 4731) and represents the first record for NT. It is a Central IWP species and ranges from W. Thailand, Indonesia, Philippines, QLD, New Caledonia, Fiji (ter Poorten 1997, 2009) and Tonga Islands, Tongatapu Island (MNHN, det. TP).

REMARKS

Unlike all its congeners, *V. sewelli* carries characteristic, regularly-placed imbricating scales on all ribs over the entire shell. It is a relatively poorly known species of which only one live specimen is known, originating from a depth of 20–30 m (New Caledonia, MNHN). Martin Shoal is located in relative close vicinity to East Timor (= Timor Leste) and Indonesia, separated by the Timor Trough (Figure 1). A record is known from the southern Indonesian Island of Sawu (colln TP 311) and this suggests that additional WA samples from the oceanic emergent offshore reefs, banks and shoals may surface, improving distributional records in the state.

Vasticardium wilsoni (Voskuil & Onverwagt, 1991)

Figures 16G–I, 20G

Acrosterigma elongatum (Bruguière, 1789) — Wilson and Stevenson 1977: 78–80, pl. 5 figs 1–4 [= paratype of *Acrosterigma wilsoni* Voskuil & Onverwagt, 1991, WAM S65194].

Trachycardium wilsoni Voskuil & Onverwagt, 1991: 64–66, pl. 3 fig. 1.

Acrosterigma wilsoni (Voskuil & Onverwagt, 1991) — Lamprell and Whitehead 1992: pl. 28 fig. 185.

Vasticardium elongatum (J.G. Bruguière, 1789) forma *wilsoni* — Huber 2010: 294, fig.

MATERIAL EXAMINED

Australia: ***Northern Territory:*** **Groote**, N.W. Gulf of Carpentaria, SE. end of Groote Eylandt, 14°12.73'S, 136°52.25'E, beached, 10.09.2009. Leg. G.M. Dally (NTM P.43243, 1 s.v.); **Anson Beagle**, N.N.E. of Darwin, Shoal Bay, western section of Gunn Point Public Beach, Tree Point, 12°19.55'S, 131°0.8'E, 13.04.1996. Leg. R.C. Willan & M.E. Chaddock (NTM P.8457, 1 s.v.); N. of Darwin, Lee Point, 12°19'S, 130°54'E, 1970. Leg. J.G. Asendorf (NTM P.45687, 1 p.v.); Darwin, central section of Casuarina Beach, adjacent to outlet of Sandy Creek, Free Beach, 12°21'S, 130°53.03'E, 06.03.1993. Leg. R.C. Willan (NTM P.30714, 1 s.v.); Darwin Harbour, near East Point, approx. 1 km W. of Dudley Point, 12°24.852'S, 130°48.692'E, 25.06.2011. Leg. R.C. Willan (NTM P.52928, 1 s.v.); **Bonaparte**, 215 miles E.N.E. of Troughton Island; 13°04'S, 129°16'E, 60 m, 23.10.1962. Leg. R.W. George, FRV 'Dorothea' Cruise 1962 (WAM S56973, 1 s.v.).

Australia: ***Western Australia:*** Kimberley, Institut Islands, W. side of Cassini Island, 13°56'S, 125°37'E, 20 m, base of wall, 22.09.1996. Leg. H. Morrison & C. Bryce, WAM Offshore Kimberley Survey 1996 (WAM S57107, 1 p.v.); Heritage Reef, 14°15'S, 125°09'E, 3–15 m, 20.08.1991. Leg. F. Wells & C. Bryce, WAM Kimberley Islands & Reefs Survey 1991, Stn 24 (WAM S56891, 1 s.v.); Leonie Island, 16°25'S, 123°03'E, intertidal, 18.11.1994. Leg. F. Wells & C. Bryce, WAM Southern Kimberley Survey 1994, Stn 6 (WAM S57097, 1 s.v.); **Canning**, Beagle Bay, 16°52'S, 122°32'E, 9 m, garden bottom, 25.08.1997. Leg. C. Bryce, Arrow Pearls Beagle Bay Fauna Survey 1997 (WAM S57095, 2 s.v.; WAM S57096, 1 s.v.); Lacepede Islands, N. side of West Island, 16°51'S, 122°07'E, intertidal sand, rock and mud, 27.08.1991. Leg. F. Wells & C. Bryce, WAM Kimberley Islands & Reefs Survey 1991, Stn 44 (WAM S56892, 1 s.v.); Coulomb Point, 17.42025°S, 122.075083°E, 11.5 m, 15.06.2008. Leg. J. Keesing, CSIRO Survey June 2008, Stn 2037(b) (WAM S44428, 1 p.v., A); Broome, intertidal sand and mud, at extreme low tide (TP 915, 1 p.v.); Lagrange Bay, Black Rocks, 18°34'S, 121°44'E, beach collection, 09.1985 (WAM S65195, 2 s.v.); **North West Shelf**, 50 miles N.E. of Adele Island, 14°59'S, 123°40'E, 100 m, 20.10.1962. Leg. R.W. George, FRV 'Dorothea' Cruise 1962 (WAM S56886, ex 723-66, 1 s.v.); 10–20 miles W. of Lagrange Bay, 18°39'S, 121°42'E, 20–45 m, 13.10.1962. Leg. R.W. George, FRV 'Dorothea' Cruise 1962 (WAM S56889, ex 731-66, 1 s.v.); 40 miles W. of Cape Jaubert, 18°56'S, 120°55'E, 40 m, 13.10.1962. Leg. R.W. George, FRV 'Dorothea' Cruise 1962 (WAM S56888, ex 711-66, 1 s.v.); S.E. of Mermaid Reef, 17°46'6.23"S, 120°43'9.12"E to 17°45'56.87"S, 120°42'56.51"E, 97–109 m, 20.06.2007. Leg. C. Whisson & O. Gomez, CSIRO RV 'Southern Surveyor' Cruise, Stn SS0507/097 (WAM S32851, 1 s.v., WAM S32852, 1 s.v.; WAM S34664, 1 s.v.), S.E. of Imperieuse Reef, 18.4602°S, 120.1447°E to 18.462°S, 120.1447°E, 80–81 m. 19.06.2007. Leg. C. Whisson & O. Gomez, CSIRO RV 'Southern Surveyor' Cruise, Stn SS0507/082 (WAM S34670, 1 s.v.); 60 miles N.W. of Bedout Island, 18°56'S, 118°28'E, 50 m, 12.10.1962. Leg. R.W. George, FRV 'Dorothea' Cruise 1962 (WAM S56887, ex 877-66, 5 s.v.); **Pilbara Nearshore/Offshore**, off Port Hedland, 20°19'S, 118°36'E, rectangular dredge, 03.10.1982. Leg. L.M. Marsh & M. Bezant, CSIRO FRV 'Soela' Cruise V 1982 (WAM S78272, 1 s.v.); Port Hedland, Cape Keraudren, low tide, 1973 (NMR993000015970, 3 p.v., paratypes); 38 nautical miles N. of Port Walcott, 19°59'S, 117°16'E, silty sand and bryozoa, 50–52 m, 15.04.1982. Leg. L.M. Marsh, CSIRO FRV 'Soela' Cruise II 1982, Stn SO2/82/54A (WAM S78278, 1 s.v.); Dampier Archipelago, Dolphin Island, W. coast near N. end, 20°25.77'S, 116°52.68'E, intertidal, 27.10.1998. Leg. S.M. Slack-Smith & C.W. Bryce, Woodside Dampier Exped. I 1998, Stn DA1/98/28 (WAM S18251, 1 s.v.); Dolphin Island, N. section of E. coast, 20°28.09'S, 116°51.91'E, intertidal, 17.10.1998. Leg. S.M. Slack-Smith & C.W. Bryce, Woodside Dampier Exped. I 1998, Stn DA1/98/02 (WAM S18212, 1 s.v.); E. side of Collier Rocks, 20°24.81'S, 116°50.68'E, intertidal, dead & live coral, 24.10.1998. Leg. S.M. Slack-Smith & C.W. Bryce, Woodside Dampier Exped. I 1998, Stn DA1/98/20 (WAM S18203, 1 s.v.); S.W. of Cohen Island, rock-armoured pipeline, 20°24.47'S, 116°46.30'E, 15–19 m, 08.09.1999. Leg. S.M. Slack-Smith et al., Woodside Dampier Exped. III 1999, Stn DA3/99/69 (WAM S22479, 1 s.v.); N. of Nelson Rocks, 20°26.51'S, 116°40.23'E, 17 m, sponges, gorgonians, large coral bommies, 07.09.1999. Leg. S.M. Slack-Smith et al., Woodside Dampier Exped. III 1999, Stn DA3/99/67 (WAM S22459, 2 s.v.); Dampier Archipelago, E. coast of West Lewis Island, 20°34.66'S, 116°39.72'E, 5 m, little coral, 04.09.1999. Leg. S.M. Slack-Smith et al., Woodside Dampier Exped. III 1999, Stn DA3/99/61 (WAM S22477, 1 s.v.); East Lewis Island, Bay on S. coast of, 20°37.50'S, 116°39.18'E, intertidal, 05.09.1999. Leg. S.M. Slack-Smith et al., Woodside Dampier Exped. III 1999, Stn DA3/99/62 (WAM S22457, 3 s.v.); East Lewis Island, W. coast, near N. point, 20°36.00'S, 116°39.00'E, intertidal, 05.09.1999. Leg. S.M. Slack-Smith et al., Woodside Dampier Exped. III 1999, Stn DAIrr/EL (WAM S22460, 1 s.v.); Georgeff Reef, 20°29.34'S, 116°36.80'E, intertidal reef, 28.08.1999. S.M. Slack-Smith et al., Woodside Dampier Exped. III 1999, Stn DA3/99/42 (WAM S22455, 1 s.v.); channel between Enderby Island & West Lewis Island, 20°35.11'S, 116°35.62'E, 18 m, sponges, soft corals & gorgonians, 02.09.1999. Leg. S.M. Slack-Smith et al., Woodside Dampier Exped. III 1999, Stn DA3/99/55 (WAM S22437, 1 s.v.; WAM S22456, 2 s.v.; WAM S22475, 1 p.v.); Rosemary Island, 20°29'S, 116°35'E, 08.1961. Leg. B. Wilson & G. Kendrick (WAM S65194, ex 732-66, 1 p.v., paratype); N. of Dampier, 20°19'33.1"S, 116°33'22.11"E, from sediment in

retrieved pipes. Leg. R. Nunn (WAM S84499, 1 p.v., A); 40 km offshore from Burrup Peninsula, 20°19'33.1"S, 116°33'22.11"E. Leg. R. Nunn (WAM S84498, 1 p.v., A); S. side of Goodwyn Island, 20°32.43'S, 116°32.68'E, 5 m, coral bommies, 31.08.1999. Leg. S.M. Slack-Smith et al., Woodside Dampier Exped. III 1999, Stn DA3/99/49 (WAM S22467, 1 fragm.); Mermaid Passage, on surface of comminuted rubble incorporating some silt, 20°42.42'S, 116°30.31'E, 21.08.1994. Leg. R.C. Willan (NTM P.21679, 4 p.v., 2 s.v.); Enderby Island, S.W. of Rocky Head, 20°37.10'S, 116°26.728'E, 14 m, sponges & soft corals, 06.09.1999. Leg. S.M. Slack-Smith et al., Woodside Dampier Exped. III 1999, Stn DA3/99/65 (WAM S22458, 2 s.v.; WAM S22478, 1 s.v.); N. of N.W. point of Eaglehawk Island, 20°38.94'S, 116°26.22'E, dive, sponges, soft corals gorgonians, 10 m, 03.09.1999. Leg. S.M. Slack-Smith et al., Woodside Dampier Exped. III 1999, Stn DA3/99/56 (WAM S22476, 2 s.v.); Dampier, by pearl divers by 'fanning the sand' in sponge garden reef with sandy holes, 35 m (TP 2012, 1 p.v.); Dampier, Back Beach, 1987 (TP 2086, 2 p.v., paratypes); Dampier (TP 2088, 1 p.v., paratype); Montebello Islands, S. of Gannet Island to E. of Delta Island, 20°27'S, 115°33'59"E, 4–6 m, grey sand, 14.08.1993. Leg. S.M. Slack-Smith, WAM Montebello Islands Survey 1993, Stn MB12 (WAM S78391, 1 s.v.); Exmouth Gulf, Hawksbill Exploration Field, 14 km E. of Muiron Islands, 21°41'S, 114°31'E, 15 m, 16.01.1994. Leg. Apache Energy (WAM S78276, 1 p.v.); Exmouth Bay (ZMA, 1 p.v.); Exmouth Gulf, by diver, on coarse sand and sponge growth, 22 m (TP 913, 1 p.v.); Exmouth Gulf, by diver, 24 m, 1998 (TP 919, 1 p.v.); Exmouth, in coarse sand and gravel, 28 m (TP 914, 1 p.v.); **Ningaloo**, Ningaloo Marine Park, 21°48.0168'S to 21°48.1218'S, 114°00.2356'E to 114°00.2791'E, 53–57 m, sponges, bryozoans, 31.01.2008. Leg. S.M. Slack-Smith, AIMS RV Solander Cruise RV4545 February 2008, Stn RVS4545-D064 (WAM S43492, 2 s.v.; WAM S43508, 1 s.v.); Ningaloo Marine Park, 21°48'5"S, 114°0'53"E, 47–50 m, rocks, rubble, rhodoliths, 12.02.2008. Leg. S.M. Slack-Smith, AIMS RV Solander Cruise RV4545 February 2008, Stn RVS4545-D142 (WAM S43507, 1 s.v.); Ningaloo Marine Park, 22°6'0"S, 113°51'50"E, 51.3–55 m, sponges, rhodoliths, 10.02.2008. Leg. S.M. Slack-Smith & M.P. Salotti, AIMS RV Solander Cruise RV4545 February 2008, Stn RVS4545-D135 (WAM S43483, 1 s.v.); Ningaloo Marine Park, off Osprey Sanctuary Zone, 22°18.263'S, 113°46.544'E to 22°18.505'S, 113°46.157'E, 55 m, 25.04.2006. Leg. M.P. Salotti, AIMS-WAM RV 'Cape Ferguson' Ningaloo Survey I, Stn CF4010&11/2006/D005 (WAM S78355, fragm.); Ningaloo Marine Park, Point Cloates, 22°47'50"S, 113°32'9"E, 81.8 m, 22.08.2008. Leg. O.A. Gomez & J. Colquhoun, AIMS-WAM RV 'Cape Ferguson' Ningaloo Survey IV August 2008, Stn SOL4769/2008/2-040SL01 (WAM S43904, 1 p.v., A).

DESCRIPTION

Shell large (height 75–110 mm), solid, slightly inequilateral, elongate-quadrate and rather inflated. Margins rounded except for straight or slightly concave posterior margin, coinciding with internal supporting radial ridge. Between 36–43 square-sided and flat-topped radial ribs, marginally serrated, forming overlapping teeth at the postero-ventral margin. Anterior ribs with low transverse rugae, median ribs laterally rugose and posterior ribs carrying oblique scales. Interstices rather narrow, deep and unsculptured. Lunule well delimited, narrow and smooth. Exterior colour cream or brown-yellow, becoming pinkish posteriorly; interior white with pink posterior margin and cream umbonal cavity.

DISTRIBUTION AND ECOLOGY

In WA, it has an exclusively inshore and continental shelf distribution (Figure 20G), occurring parapatrically alongside its sister species, *V. elongatum,* which is confined to the oceanic emergent reefs of the shelf margin (see also under that species). Its occurrence in NT is well established by the presence of six NTM/WAM samples, the largest of which (NTM P.43243, H 110 mm) is from the Gulf of Carpentaria, S.E. of Groote Eylandt.

REMARKS

The type material selected by Voskuil and Onverwagt (1991) is a composite of two taxa: the paratype from Indonesia, Moluccas (RMNH.MOL.56585, ex colln Geologisch Museum Wageningen, 1941; Hylleberg 2004: 872, unnumbered fig.) corresponds morphologically with *V. elongatum*, but not *V. wilsoni* (see under *V. elongatum* for assigning specific status to all taxa in the *elongatum* complex). Vidal (1993: 45) considered it 'rather different from the holotype'. A paratype labelled 'Fiji Islands' (Leg. H. Dabbert, RMNH.MOL.56584; Hylleberg 2004: 872, unnumbered fig.) does belong to *V. wilsoni*; regarding its provenance, Jeroen Goud (RMNH) communicated (e-mail 23.03.2015) that the origin of the Dabbert material is unreliable and should be treated as untrustworthy. Although few northeast QLD samples are listed by Voskuil and Onverwagt (1991), Vidal (1993) limits the E. end of the distribution to the Torres Strait. As no supplementary trustworthy QLD material has been encountered and in the absence of other non-Australian records, *V. wilsoni* is considered an endemic Dampierian species. *Vasticardium wilsoni* is easily separated from the related *V. coralense* (Vidal, 1993) by its elongate-quadrate shape and by its straight to slightly concave posterior margin, coinciding with a strong internal supporting radial ridge (Figure 16H, arrow).

Cardium (*Trachycardium*) *serricostatum* Melvill & Standen, 1899 has been described based on material from Torres Strait: between Ormans Reef and the 'Brothers Island', 6–7 fms, 18.08.1888 (stn 4) and Murray Island, Mèr, fringing reef (stn 13). Prof. A.C.

Haddon Exped. 1888–1889. A syntype (NHMUK 1899.2.23.10; Figures 16E–F) is a rather worn left valve, has a height of 21.5 mm and 40 ribs. The accompanying labels only refer to 'Torres Straits', include the word 'type' and the source: A.C. Haddon. It closely matches the type figure and is the appropriate size (20 mm). This valve does not have an internal supporting radial ridge (present also in the juvenile stage of *V. wilsoni*) and has a rounded posterior margin. Vidal (1993: 45) concluded that it represents 'a juvenile specimen of *V. elongatum*'. This is unlikely as it would be well outside the known distribution range of *V. elongatum* (see under that species). Compared to the related *V. coralense* (Vidal, 1993) from New Caledonia, QLD material has a higher rib number (39–42, n = 4 versus 34–38, n = 26), broader and deeper interstices, much better developed ribs on the posterior slope and is much less colourful. QLD samples also lack the typical pink coloured internal margin of *V. coralense*. WAM S78076 (ex 4777-68), figured by Vidal (1993: pl. 1 fig. 2, pl. 2 fig. 4) and Wells and Bryce (1985: pl. 63 fig. 600), originates from QLD (Cape York) and agrees with this material. Based on the available samples, *V. serricostatum* is tentatively considered a distinct species, separated from *V. wilsoni* by a more rounded shape, lacking an internal supporting ridge and separated from *V. coralense* by a higher rib number, more prominent ribbing and a different coloration.

EXCLUDED SPECIES

1. *Vepricardium incarnatum* (Reeve, 1844)

   A specimen of *V. incarnatum*, erroneously identified by Voskuil and Onverwagt (1988: pl. 2 figs 1–2) as *V. multispinosum* (Sowerby, 1841) was stated to originate from 'Dampier Archipelago, W. Australia' (now in colln TP 2746). The misidentification was noted by Vidal (2000). This locality is considered erroneous as no other WA records exist. The true distribution of *V. incarnatum* is limited to the Vietnam — Philippines — N. Indonesia region. A shell said to come from QLD, figured by Lamprell and Whitehead (1992: fig. 184) and identified as *V. incarnatum* refers to *V. coronatum* (Schröter, 1786), which also does not occur in Australia.

2. *Acrosterigma abrolhense* Vidal, 1999

   This species was originally described from the Houtman Abrolhos Islands, a small series of low coral islands located in the Western Overlap Zone, at the confluence of the Flindersian Province and the Dampierian Province. *Acrosterigma abrolhense* was compared with its closest species, *A. cygnorum* (Deshayes, 1855) by Vidal (1999). We revisited this species during the course of our work (the first author examined TP 2037 from Shark Bay, possibly the most northern record; also WAM S77961, S77962, S77963 and S78325 from the Houtman Abrolhos Islands which all belong to *cygnorum* as well as S78390, S79279 and S79280 from off Dongara). We find an alternate interpretation more likely and propose that *A. abrolhense* represents both juvenile *A. cygnorum* material, but also northern-endpoint range variation within *A. cygnorum*, with an acceptable level of intraspecific variation. For example, the rib number for *abrolhense* given by Vidal (1999), 43–46, falls within the rib number of *cygnorum*, 36–47, given by the same author. Therefore we propose that *A. abrolhense* be recognised as a syn. nov. of *A. cygnorum*.

RESULTS

WESTERN AUSTRALIAN TRENDS IN CARDIIDAE

Sixty-eight species of cardiid are recognised from WA and updated nomenclature is provided for taxa previously recognised by Wilson and Stevenson (1977). An overview of the cardiid species is tabulated as follows: AIOT (Table 3), WA (Table 4), QLD species not reported from WA (Table 5) and South/East and North/East end of ranges of WA species (Table 6). The newly described species are all somewhat restricted in their distribution, while new records that are not new species, represent wide-ranging members of the IWP fauna. The four newly described species are *Acrosterigma extremattenuatum* sp. nov. (Figures 13–14), *Ctenocardia pilbaraensis* sp. nov. (Figures 8A–L), *Microcardium scabrosum* sp. nov. (Figures 3I–M, 4A–F) and *Pratulum occidentale* sp. nov. (Figures 5A–F, 6A–M); all of these new species are found in deeper waters. *Pratulum occidentale* sp. nov. is endemic to WA (Figure 17F). The other three new species, *C. pilbaraensis* sp. nov., *A. extremattenuatum* sp. nov., and *M. scabrosum* sp. nov. are found inshore (Pilbara, Figure 18C and latter two from northern Australia, Figures 20B and 17E, respectively). Sixteen taxa are new records for Western Australia and 14 are new records for Australia. No new records are presented for southern cardiid taxa. Records confirm the well known distinction between inshore/offshore areas of the northwest shelf, with sixteen taxa found restricted to offshore islands and shoals (e.g. *Vasticardium philippinense, V. elongatum, Corculum cardissa, Ctenocardia fornicata, C. gustavi*), and a smaller cohort found exclusively inshore (e.g. *A. extremattenuatum* sp. nov., *V. wilsoni*, *C. pilbaraensis* sp. nov.) (Figure 21). Previous records collated here document seven species of giant clam in WA.

COMPARISON BETWEEN WESTERN AUSTRALIAN AND AUSTRALIAN INDIAN OCEAN TERRITORIES (AIOT) CARDIIDAE

While 68 species of cardiid are recognised from WA only a subset of this fauna, 16 species in total, are known from the Christmas and Cocos-Keeling Islands of the AIOT (Table 3). Nearly all taxa reported from AIOT are also known from WA and nearly all represent

wide-ranging members of the IWP fauna found offshore in WA. Two taxa from Cocos-Keeling Islands represent new records for Australia: *Fulvia dulcis* and *'Fulvia' lineonotata*. Eleven taxa are reported from Christmas Island while 14 taxa are reported from Cocos-Keeling (*Afrocardium richardi* and *Fragum mundum* are absent from Cocos-Keeling, while *Fragum fragum, Fragum sueziense, Fulvia australis, Fulvia dulcis* and *'Fulvia' lineonotata* are absent from Christmas Island). Six giant clam species are reported from Christmas and Cocos-Keeling Islands of the AIOT.

COMPARISON BETWEEN WESTERN AUSTRALIAN AND NORTHERN TERRITORY CARDIIDAE

Twenty-five cardiids are recognised from the NT, including two of the newly described species, *Acrosterigma extremattenuatum* sp. nov. and *Microcardium scabrosum* sp. nov. (Table 4). Updated nomenclature is provided. Seven new records for the NT were found; *Afrocardium richardi* (Figure 19A), *Fragum whitleyi* (Figure 18F) *Frigidocardium torresi* (Figure 17C), *Fulvia australis* (Figure 19C), *Fulvia hungerfordi* (Figure 19D), *Vasticardium philippinense* (Figure 20F) and *V. sewelli*; all are well known members of the IWP fauna and in WA, most are found on the offshore reefs. Previous records document four species of giant clam in the NT.

COMPARISON BETWEEN WESTERN AUSTRALIAN AND QUEENSLAND CARDIIDAE

Eighteen species of cardiid from ten different genera are recognised from QLD that are not yet known in WA (Table 5, based on material verified by the first author). Four of these are new records for Queensland; *Afrocardium exochum*, *Frigidocardium* sp. nov. 1, *Fulvia fragiformis* and *F. hungerfordi*. All of these new records were found in non-QM collections.

TABLE 3 Cardiidae species from the Australian Indian Ocean Territories (IOT) of Christmas Island and Cocos (Keeling) Islands, based on material verified by the authors or with literature data.

Species	Christmas Island	Cocos (Keeling) Islands
Afrocardium richardi (Audouin, 1826)	NHMUK 1911.2.26.14-15 (syntypes of *Cardium rubescens* E.A. Smith, 1911)	—
Corculum cardissa (Linnaeus, 1758)	Tan and Low (2014)	WAM S57058
Fragum fragum (Linnaeus, 1758)	—	WAM S57053-S57057, S57059-S57060, S57069, S57080, S79511
Fragum mundum (Reeve, 1845)	UF 337833	—
Fragum sueziense (Issel, 1869)	—	UF 338198
Fulvia australis (G.B. Sowerby II, 1834)	—	UF 338200 (mixed sample)
Fulvia dulcis (Deshayes, 1863)	—	UF 338200 (mixed sample; first record for Australia)
'Fulvia' lineonotata Vidal, 1994	—	UF 338200 (mixed sample; first record for Australia)
Tridacna crocea Lamarck, 1819	Tan and Low (2014)	WAM S57200, S57215, S57231
Tridacna derasa (Röding, 1798)	Tan and Low (2014)	USNM 654256
Tridacna gigas (Linnaeus, 1758)	Tan and Low (2014)	Tan and Low (2014); Wells (1994)
Tridacna maxima (Röding, 1798)	WAM S57204, S57207-S57208, S57210-S57211, S57217-S57219, S76780-S76781	WAM S57216
Tridacna noae (Röding, 1798)	WAM S57203, S57209, S57212, S57233	WAM S57213, S57214, S57224-S57225, S76786, S84351
Tridacna squamosa Lamarck, 1819	Tan and Low (2014); Wells et al. (1990)	WAM S57232
Vasticardium angulatum (Lamarck, 1819)	Tan and Low (2014)	WAM S56938-S56940, S56936-S56937, S56991-S56992
Vasticardium philippinense (Hedley, 1899)	WAM S56834-S56845, S57125, TP 4405	WAM S56984-S56990, S76771

TABLE 4 Western Australia Cardiidae species as currently recognised (Tridacninae included). NT, verified record(s) known from the Northern Territory; S.A., endemic southern Australia; WA, endemic Western Australia; IWP, Indo-West Pacific; NOR, so far exclusively known from the northern offshore reefs and shoals.

No	Species	Distribution	NOR	NT	Source WA Presence
1	*Acrosterigma biradiatum* (Bruguière, 1789)	IWP		•	Wilson and Stevenson (1977)
2	*Acrosterigma cygnorum* (Deshayes, 1855)	S.A.			Wilson and Stevenson (1977)
3	*Acrosterigma dianthinum* (Melvill & Standen, 1899)	IWP	•		Present study
4	*Acrosterigma extremattenuatum* sp. nov.	N.Austr.		•	Wilson and Stevenson (1977) (as *L. attenuatum*)
5	*Acrosterigma impolitum* (G.B. Sowerby II, 1834)	IWP		•	Wilson and Stevenson (1977)
6	*Acrosterigma marielae* Wilson & Stevenson, 1977	WA			Wilson and Stevenson (1977)
7	*Acrosterigma punctolineatum* Healy & Lamprell, 1992	IWP		•	(Willan et al. 2015)
8	*Acrosterigma simplex* (Spengler, 1799)	IWP			Present study
9	*Acrosterigma suduirauti* Vidal & ter Poorten, 2007	IWP	•		Present study
10	*Acrosterigma transcendens* (Melvill & Standen, 1899)	IWP			Wilson and Stevenson (1977)
11	*Acrosterigma variegatum* (G.B. Sowerby II, 1840)	IWP			Present study
12	*Afrocardium richardi* (Audouin, 1826)	IWP		•	Present study
13	*Corculum cardissa* (Linnaeus, 1758)	IWP	•		Wells and Slack-Smith (1986)
14	*Ctenocardia fornicata* (G.B. Sowerby II, 1840)	IWP	•		Present study
15	*Ctenocardia gustavi* Vidal & Kirkendale, 2007	IWP	•		(Willan et al. 2015)
16	*Ctenocardia pilbaraensis* sp. nov.	IWP			Wilson and Stevenson (1977) (as *C. fornicata*)
17	*Ctenocardia virgo* (Reeve, 1845)	IWP		•	Wilson and Stevenson (1977)
18	*Fragum erugatum* (Tate, 1889)	IWP			Wilson and Stevenson (1977)
19	*Fragum fragum* (Linnaeus, 1758)	IWP			Wilson and Stevenson (1977)
20	*Fragum mundum* (Reeve, 1845)	IWP			(Willan et al. 2015)
21	*Fragum* sp. aff. *scruposum* (Deshayes, 1855)	IWP			Present study
22	*Fragum sueziense* (Issel, 1869)	IWP			ter Poorten (2009)
23	*Fragum unedo* (Linnaeus, 1758)	IWP			Wilson and Stevenson (1977)
24	*Fragum whitleyi* Iredale, 1929	IWP		•	Present study
25	*Freneixicardia victor* (Angas, 1872)	IWP			Wilson and Stevenson (1977)
26	*Frigidocardium eos* (Kuroda, 1929)	IWP			Huber and ter Poorten (2007)
27	*Frigidocardium helios* ter Poorten & Poutiers, 2009	IWP			Present study
28	*Frigidocardium iris* Huber & ter Poorten, 2007	IWP			Huber and ter Poorten (2007)
29	*Frigidocardium torresi* (E.A. Smith, 1855)	IWP		•	ter Poorten (2009)
30	*Fulvia aperta* (Bruguière, 1789)	IWP			Wilson and Stevenson (1977)
31	*Fulvia australis* (G.B. Sowerby II, 1834)	IWP		•	(Willan et al. 2015)
32	*Fulvia boholensis* Vidal, 1994	IWP			Vidal (1994)
	**Fulvia hungerfordi* (G.B. Sowerby III, 1901)			•	*(not in WA)
33	*Fulvia laevigata* (Linnaeus, 1758)	IWP		•	ter Poorten (2009)
34	*Fulvia scalata* Vidal, 1994	IWP			Vidal (1994)
35	*Fulvia tenuicostata* (Lamarck, 1819)	S.A.			Wilson and Stevenson (1977)
36	*Fulvia undatopicta* (Pilsbry, 1904)	IWP			Present study
37	*'Laevicardium' lobulatum* (Deshayes, 1855)	IWP	•		Present study
38	*Lunulicardia tumorifera* (Lamarck, 1819)	WA			Wilson and Stevenson (1977) (as *L. hemicardium*)
39	*Lunulicardia retusa* (Linnaeus, 1767)	IWP		•	Wilson and Stevenson (1977)
40	*Lyrocardium aurantiacum* (A. Adams & Reeve, 1850)	IWP			Present study
41	*Lyrocardium lyratum* (G.B. Sowerby II, 1840)	IWP		•	Wilson and Stevenson (1977)
42	*Maoricardium fraseri* (Garrard, 1963)	N.Austr.			Wilson and Stevenson (1977)

No	Species	Distribution	NOR	NT	Source WA Presence
43	*Maoricardium setosum* (Redfield, 1848)	IWP		•	Wilson and Stevenson (1977)
44	*Microcardium sakuraii* (Habe, 1961)	IWP	•		ter Poorten (2009)
45	*Microcardium scabrosum* sp. nov.	N.Austr.		•	Poutiers (1992)
46	*Microfragum festivum* (Deshayes, 1855)	IWP	•		Willan (2005)
47	*Nemocardium probatum* (Iredale, 1927)	N.Austr.		•	Wilson and Stevenson (1977)
48	*Pratulum occidentale* sp. nov.	WA			Poutiers (1992)
49	*Pratulum thetidis* (Hedley, 1902)	S.A.			Wilson and Stevenson (1977)
50	*Trifaricardium morrisoni* ter Poorten & Huber, 2007	WA			ter Poorten and Huber (2007)
51	*Trifaricardium nomurai* Kuroda & Habe, 1951	IWP	•		ter Poorten and Huber (2007)
52	*Vasticardium angulatum* (Lamarck, 1819)	IWP		•	Wilson and Stevenson (1977)
53	*Vasticardium dupuchense* (Reeve, 1845)	WA			Wilson and Stevenson (1977)
54	*Vasticardium elongatum* (Bruguière, 1789)	IWP	•		Present study
55	*Vasticardium fultoni* (G.B. Sowerby III, 1916)	WA			Wilson and Stevenson (1977)
56	*Vasticardium mindanense* (Reeve, 1844)	IWP	•		Present study
57	*Vasticardium philippinense* (Hedley, 1899)	IWP	•		Lamprell and Whitehead (1992)
58	*Vasticardium sewelli* (Prashad, 1932)	IWP	•	•	Present study
59	*Vasticardium vertebratum* (Jonas, 1844)	IWP		•	Wilson and Stevenson (1977)
60	*Vasticardium wilsoni* (Voskuil & Onverwagt, 1991)	N.Austr.		•	Voskuil and Onverwagt (1991)
61	*Vepricardium multispinosum* (G.B. Sowerby II, 1839)	IWP		•	Wilson and Stevenson (1977)
62	*Hippopus hippopus* (Linnaeus, 1758)	IWP			Rosewater (1965)
63	*Tridacna* (*Chametrachea*) *crocea* Lamarck, 1819	IWP	•		Wells and Slack-Smith (1986)
64	*Tridacna* (*Chametrachea*) *maxima* (Röding, 1798)	IWP		•	Rosewater (1965)
65	*Tridacna* (*Chametrachea*) *noae* (Röding, 1798)	IWP			Penny and Willan (2014)
66	*Tridacna* (*Chametrachea*) *squamosa* Lamarck, 1819	IWP		•	Hedley (1921)
67	*Tridacna* (*Tridacna*) *derasa* (Röding, 1798)	IWP	•	•	Bryce and Whisson (2009)
68	*Tridacna* (*Tridacna*) *gigas* (Linnaeus, 1758)	IWP	•	•	Wells and Slack-Smith (1986)

TABLE 5 Queensland Cardiidae species so far not reported from WA, based on personally verified material.

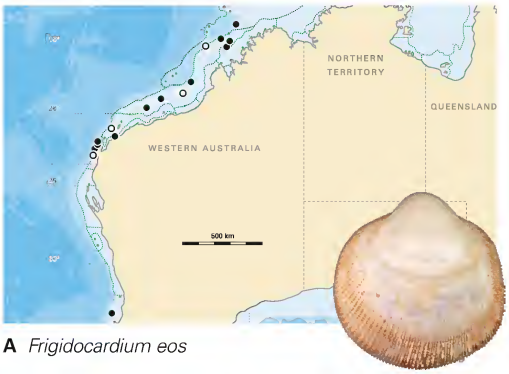
No	Species	Source QLD presence	New QLD record
1	*Acrosterigma attenuatum* (G.B. Sowerby II, 1841)	ZMA, TP	
2	*Acrosterigma hobbsae* Vidal, 1999	NTM	
3	*Acrosterigma kerslakae* Healy & Lamprell, 1992	AMS, MNHN, NTM, WAM	
4	*Acrosterigma maculosum* (W. Wood, 1815)	NTM, ZMA, TP	
5	*Afrocardium exochum* (Melvill & Standen, 1907)	MNHN	•
6	*Fragum vanuatuense* ter Poorten, 2015	NTM	
7	*Frigidocardium* sp. nov. 1	WAM	•
8	*Fulvia fragiformis* Vidal, 1994	NTM	•
9	*Fulvia hungerfordi* (G.B. Sowerby III, 1901)	WAM	•
10	*Fulvia nienkeae* ter Poorten, 2012	NHMUK, NTM, ZMA	
11	*Lunulicardia auricula* (Niebuhr in Forsskål, 1775)	Lamprell and Healy (1998: fig. 739)	
12	*Lunulicardia hemicardium* (Linnaeus, 1758) (in agreement with forma *guichardi*)	MNHN, NTM, WAM	
13	*Maoricardium pseudolatum* Voskuil & Onverwagt, 1991	MNHN, NTM, TP	
14	*Microfragum subfestivum* Vidal & Kirkendale, 2007	MNHN, NMR, NTM, WAM, TP	
15	*Trifaricardium* sp. nov. 1 *sensu* Poutiers, 1992	AMS, WAM	
16	*Vasticardium serricostatum* (Melvill & Standen, 1899)	NTM, WAM, TP	
17	*Vasticardium flavum* (Linnaeus, 1758)	NTM, ZMA, TP	
18	*Vasticardium pectiniforme* (Born, 1780)	NTM, WAM, ZMA, TP	

TABLE 6 South/East and North/East end of ranges of Western Australia Cardiidae species. Only trustworthy records are included (i.e. with detailed locality data and known collector). More samples are given when nearby localities are involved. For species known from a single sample only the South/East end is given. Subfossil material is excluded. References to figured samples are given in bold type; an asterisk (*) indicates that the sample is figured by Wilson and Stevenson (1977). Total number of examined WA cardiid samples: 1874 (main sources: WAM, TP, NTM, AMS and ZMA).

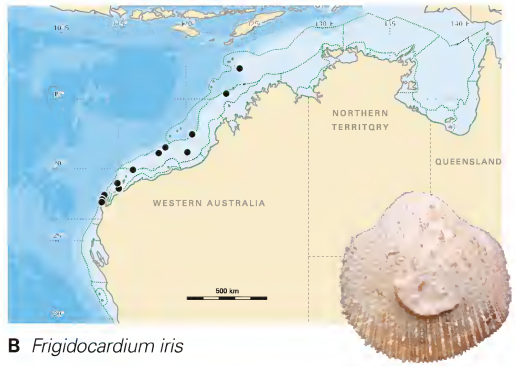
No.	Species	WA S./E. end of distribution	WA N./E. end of distribution
1	*Acrosterigma biradiatum*	Ningaloo, 22°06' S, 113°52'E (WAM S43486)	Yankawingarri Island, 14°09'S, 125°39'E (WAM S56797; WAM S56798); Ashmore Reef, 12°12'S, 123°03'E (WAM S75358)
2	*A. cygnorum*	Recherche Archipelago, 34°06'S, 123°11'E (WAM S79235)	Houtman Abrolhos Islands, 28°22'S, 114°16'E (WAM S77963); 28°22'S, 113°54'E (WAM S78325)
3	*A. dianthinum*	Scott Reef, 14°02.526'S, 121°45.688'E (WAM S31136)	Ashmore Reef, 12°12'S, 12° 123°09'E (WAM S91668); Vulcan Shoal, 12°48'S, 124°16'E (WAM S91854, **Figures 12C–F**)
4	*A. extremattenuatum* sp. nov.	Ningaloo, 21°49.876'S, 113°58.407'E (WAM S84455)	Lagrange Bay, 18°39'S, 121°42'E (WAM S56792)
5	*A. impolitum*	Houtman Abrolhos Islands, 28°24'S, 113°45'E (WAM S79330); 28°50'S, 113°50'E (WAM S15704)	Joseph Bonaparte Gulf, 12°44'S, 128°52'E (NTM P.49882)
6	*A. marielae*	Bald Island, 35.1784°S, 118.6320°E (WAM S29282)	Ningaloo, 22.0795°S, 113.7960°E (WAM S29299)
7	*A. punctolineatum*	Mermaid Reef, 17°46'S, 120°43'E (WAM S32858)	Cassini Island, 13°57'S, 125°39'E (WAM S58854); Long Reef, 14°01'S, 125°44'E (WAM S56960)
8	*A. simplex*	Montebello Islands, 20°30'S, 115°32'E (WAM S78358, **Figures 12U–X**)	Cartier Island, 12°32'S, 123°34'E (TP 1339)
9	*A. suduirauti*	Imperieuse Reef, 17°36'S, 118°59'E (WAM S32883, **Figures 12O–R**)	—
10	*A. transcendens*	Ningaloo, 22°06'S, 113°49'E (WAM S43902)	Troughton Island, 13°57'S, 125°52'E (WAM S56894)
11	*A. variegatum*	Ningaloo, 22°46'15"S, 113°38'4"E (WAM S43505, **Figures 12S–T**)	Ashmore Reef, 12°12'S, 123°03'E (WAM S75354)
12	*Afrocardium richardi*	North West Cape, 21°50'S, 113°46'E (WAM S15920, **Figures 7A–B**)	Broome, 17°58'S, 122°14'E (WAM S57165, **Figures 7C–D**)
13	*Corculum cardissa*	Imperieuse Reef, 17°30'S, 118°57'E (WAM S68277); Clerke Reef, 17°22'S, 119°21'E (WAM S39931)	Cartier Island, 12°32'S, 123°33'E (NTM P.222, **Figures 9M–P**)
14	*Ctenocardia fornicata*	Scott Reef, 13°59'S, 121°46'E (WAM S39930, **Figures 8P–T**)	—
15	*C. gustavi*	Scott Reef, 13°58'S, 121°51'E (WAM S39929, **Figures 9C–D**)	Hibernia Reef, 11°58'S, 123°22'E (NTM P.13187); 11°59'S, 123°22'E (NTM P.23197)
16	*C. pilbaraensis* sp. nov.	W. of Shark Bay, 25°51'S, 113°03'E (WAM S78046)	Lacepede Island, 16°52'S, 122°09'E (WAM S57168)
17	*C. virgo*	Houtman Abrolhos Islands, 28°49'S, 113°47'E (WAM S66883)	Troughton Island, 13°15'S, 128°19'E (WAM S57003)
18	*Fragum erugatum*	Point Peron, 32°16'S, 115°41'E (WAM S66925)	Dampier Archipelago, 20°29'S, 116°52'E (WAM S18229; WAM S18232); 20°23.98'S, 116°49.52'E (WAM S18245)
19	*Fragum fragum*	Cardabia, 23°06'S, 113°48'E (WAM S79486, ex 2374-67)*; Warroora Station, 23°29'S, 113°48'E (WAM S79484)	Ashmore Reef, 12°11'S, 122°58'E (WAM S57061); Hibernia Reef, 11°55'S, 123°28'E (WAM S57070)
20	*F. mundum*	Dampier Archipelago, 20°29'S, 116°32'E (WAM S79509, **Figures 10E–H**)	Ashmore Reef, 12°17'S, 123°08'E (WAM S75212, **Figures 10A–D**); Cartier Island, 12°32'S, 123°34'E (NTM P.54210, **Figures 10K–L**)

No.	Species	WA S./E. end of distribution	WA N./E. end of distribution
21	*F.* sp. aff. *scruposum*	Houtman Abrolhos Islands, 28°26'S, 113°43'E (WAM S78123, **Figures 10M–N**)	—
22	*F. sueziense*	Houtman Abrolhos Islands, 28°42'S, 113°46.5'E (WAM S84480)	Broome, 17°58'S, 122°14'E (WAM S57164)
23	*F. unedo*	Shark Bay, 26°13'S, 113°41'E (WAM S79603)	Sir Graham Moore Islands, 13°52'S, 126°36'E (WAM S57047)
24	*F. whitleyi*	Houtman Abrolhos Islands, 28°42'S, 113°46'E (WAM S133366)	Ashmore Reef, 12°17'S, 123°08'E (WAM S91688, **Figures 10P–Q**);
		Dampier Archipelago, 20°29'S, 116°35'E (WAM S13359)	Ashmore Reef, 12°16'S, 123°06'E (WAM S84271)
25	*Freneixicardia victor*	Ningaloo, 22°10.661'S, 113°48.937'E (WAM S79726); 22°10.156'S, 113°50.282'E (WAM S79727)	Adele Island, 14°34'S, 122°55'E (WAM S32874)
26	*Frigidocardium eos*	Bunbury, 33°00'S, 114°52'E (WAM S84345, **Figures 2E–F**);	Kulumburu, 13°28'S, 124°01'E (WAM S32879)
		Point Cloates, 22°52'S, 113°29'E (WAM S15917, **Figures 2A–D**)	
27	*F. helios*	Point Cloates, 22.8487°S, 113.5110°E (WAM S29441)	Onslow, 21°31'S, 114°40'E (WAM S78145, **Figures 3A–B**)
28	*F. iris*	Ningaloo, 22°15'46"S, 113°44'58"E (WAM S78135)	W. of Cartier Island, 12°43'S, 123°58'E (NTM P.8600)
29	*F. torresi*	Dampier Archipelago, 19°23'S, 117°21'E (WAM S78287)	Broome, 17°58'S, 122°14'E (WAM S57167);
			Clerke Reef, 17°20'S, 119°10'E (WAM S15913; WAM S15915)
30	*Fulvia aperta*	Point Cloates, 22°37'S, 113°38.5'E (WAM S84240)	Mission Bay, 14°06'S, 126°42'E (WAM S56823)
31	*F. australis*	S. of Ningaloo, 24°00.9114'S, 113°26.4864'E (WAM S84236)	Malcolm Island, 14°31'S, 125°54'E (WAM S66929)
32	*F. boholensis*	Dampier Archipelago, 20°42.42'S, 116°30.31'E (NTM P.54198, **Figures 11G–J**)	—
33	*F. laevigata*	Shark Bay, 26°09'S, 113°09'E (WAM S66948)	Tranquil Bay, 13°56'S, 127°18'E (WAM S56805)
		Shark Bay, Monkey Mia (ZMA.MOLL.80911)	
34	*F. scalata*	18°47'S, 117°58'E (WAM S56827, WAM S57158)	Mermaid Reef, 17°29'S, 120°28'E (WAM S34673, **Figures 11P–S**)
35	*F. tenuicostata*	Esperance, 33°52'S, 121°54'E (WAM S66932)	Houtman Abrolhos Islands, 28°43'S, 113°47'E (WAM S82989)
36	*F. undatopicta*	Muiron Islands, 21°41'S, 114°31'E (WAM S78338, **Figures 11V–Y**)	Broome, 17°58'S, 122°14'E (WAM S57166)
37	*Lunulicardia tumorifera*	Shark Bay, 26°13'S, 113°47'E (WAM S66835)	Exmouth Gulf, 22°27'S, 114°20'E (WAM S66834);
			Point Cloates, 22°37'S, 113°38.5'E (WAM S66837)
38	*L. retusa*	Cockburn Sound, 32°13'S, 115°42'E (WAM S66915)	Vansittart Bay, 14°04'S, 126°20'E (WAM S57050); 14°02'S, 126°18'E (WAM S57075)
39	*Lyrocardium aurantiacum*	Ningaloo, 22°18.263'S, 113°46.544'E (WAM S78132)	Dampier Archipelago, 19°55'S, 116°36'E (WAM S78055, **Figures 7L–M**)
40	*L. lyratum*	Houtman Abrolhos Islands, 28°49'S, 113°47'E (WAM S66936)	Institut Islands, 13°56'S, 125°38'E (WAM S57098); 13°56'S, 125°39'E (WAM S57099; WAM S57100)
41	*Maoricardium fraseri*	N. of Cape Lambert, 20°01'S, 117°13'E (WAM S66941)	N.E. of Adele Island, 14°52'S, 123°52'E (WAM S56801)
42	*M. setosum*	Exmouth Gulf, 22°18'S, 114°08'E (WAM S66944, ex 70-67)*	Joseph Bonaparte Gulf, 14°34'S, 128°27'E (WAM S57143);
			W. of Troughton Island, 13°57'S, 125°52'E (WAM S56783)
43	*Microcardium sakuraii*	Mermaid Reef, 17°12'S, 119°35'E (WAM S32885)	Augustus Island, 13°33.3'S, 122°54.5'E (WAM S57163);
			Browse Island, 14°06'S, 123°33'E (WAM S57142)
44	*M. scabrosum* sp. nov.	Ningaloo, 22.0795°S, 113.7960°E (WAM S29448)	N.W. of Port Hedland, 18°47'S, 117°58'E (WAM S15906, **Figures 3I–J**)

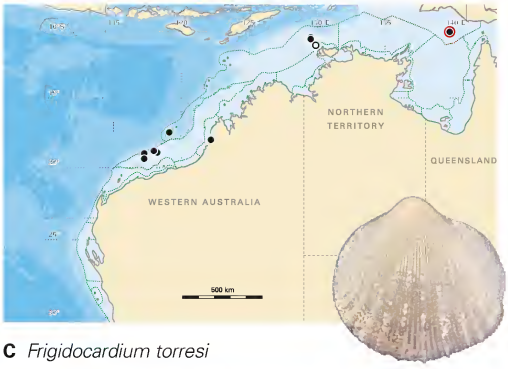
No.	Species	WA S./E. end of distribution	WA N./E. end of distribution
45	*Microfragum festivum*	Clerke Reef, 17°20'S, 119°20'E (NTM P.40065); 17°16'S, 119°22'E (WAM S40376, **Figures 9E–H**)	Ashmore Reef, 12°13'S, 122°58'E (NTM P.24387)
46	*Nemocardium probatum*	Lancelin, 30°58'S, 114°49'E (WAM S78233); S. of Houtman Abrolhos Islands, 29°08'S, 113°57'E (WAM S66934)	N.E. of Troughton Island, 13°12'S, 128°37'E (WAM S56998)
47	*Pratulum occidentale* sp. nov.	N. of Bluff Point, 27°18'S, 113°16'E (WAM S15916, **Figures 6A–B**; WAM S70653)	N.W. of Cape Leveque, 15°12'S, 121°26'E (WAM S34674)
48	*P. thetidis*	Esperance Bay, 33°52'S, 121°54'E (WAM S84264)	W. of Cliff Head, 29°32'S, 114°16'E (WAM S15919)
49	*'Laevicardium' lobulatum*	Clerke Reef, 17°18'S, 119°22'E (WAM S68164, **Figures 7N–Q**)	—
50	*Trifaricardium morrisoni*	N.W. of Port Hedland, 18°47'S, 117°58'E (WAM S15903, paratype)	Cape Leveque, 14°52.2'S, 121°41.7'E (WAM S15911, paratype)
51	*T. nomurai*	Rowley Shoals, 17°20'S, 119°10'E (WAM S29459, **Figure 7S**; WAM S39961, **Figures 7T–U**)	—
52	*Vasticardium angulatum*	Exmouth Gulf, 21°53'S, 114°09'E (WAM S84324)	Reveley Island, 14°22'S, 127°50'E (WAM S84354)
53	*V. dupuchense*	Carnarvon, 23°29'S, 113°48'E (WAM S84362)	Broome, 17°58'S, 122°14'E (WAM S56906; WAM S56907)
54	*V. elongatum*	Ashmore Reef, 12°11'S, 122°58'E (WAM S56890, **Figures 15A–B**); 12°11'S, 123°03'E (WAM S75817)	—
55	*V. fultoni*	Point Cloates, 22°30'S, 113°42'E (WAM S82974); 22°29'S, 113°42'E (WAM S84469)	Tranquil Bay, 13°56'S, 127°18'E (WAM S56902)
56	*V. mindanense*	Ashmore Reef, 12°14'S, 122°58'E (NTM P.10066, **Figures 15C–E**)	—
57	*V. philippinense*	Imperieuse Reef, 17°32'S, 118°58'E (WAM S68174)	Martin Shoal, 9°37'S, 128°53'E (NTM P.55827)
58	*V. sewelli*	Martin Shoal, 9°36.64'S, 128°52.6'E (TP 4679, **Figures 16A–D**)	—
59	*V. vertebratum*	Dunsborough, 33°37'S, 115°06'E (WAM S84473, ex N-2357)*	Tranquil Bay, 13°56'S, 127°18'E (WAM S56850)
60	*V. wilsoni*	Ningaloo, 22°48'S, 113°32'E (WAM S43904)	Heritage Reef, 14°15'S, 125°09'E (WAM S56891); Institut Islands, 13°56'S, 125°37'E (WAM S57107)
61	*Vepricardium multispinosum*	S. of Ningaloo, 23°28'S, 113°47'E (WAM S84272)	Joseph Bonaparte Gulf, 13°04'S, 129°02'E (WAM S56779); N.E. of Adele Island, 14°52'S, 123°52'E (WAM S56790)
62	*Hippopus hippopus*	Clerke Reef, 17°23'S, 119°20'E (WAM S33232); Imperieuse Reef (WAM field observations, 2014 trip)	Troughton Island, 13°45'S, 126°11'E (WAM S57187)
63	*Tridacna crocea*	Clerke Reef, 17°23'S, 119°20'E (WAM S33251)	Cartier Island, 12°31'S, 123°33'E (WAM S57196; WAM S57234)
64	*T. maxima*	Houtman Abrolhos Islands, 28°43'S, 113°47'E (WAM S66949); 28°53'S, 113°51'E (WAM S66951)	Jar Island, 14°09'S, 126°14'E (WAM S57192)
65	*T. noae*	Shark Bay, 24°59'S, 113°07'E (WAM S66952)	Montebello Islands, 20°23'S, 115°33'E (WAM S87944)
66	*T. squamosa*	Coral Bay, 23°11'S, 113°46'E (NTM P.47918); Muiron Islands, 21°38'S, 114°24'E (WAM S66954)	Troughton Island, 13°45'S, 126°11'E (WAM S57223)
67	*T. derasa*	Mermaid Reef (Bryce and Whisson, 2009); Imperieuse Reef (WAM field observations, Stn 164)	Ashmore Reef (LK field observations, 2013); Hibernia Reef (Bryce, field observation)
68	*T. gigas*	Clerke Reef, 17°20'S, 119°21'E (WAM S29483); Imperieuse Reef (WAM field observations, Stn 164)	Hibernia Reef, 11°58'S, 123°19'E (WAM S57197)



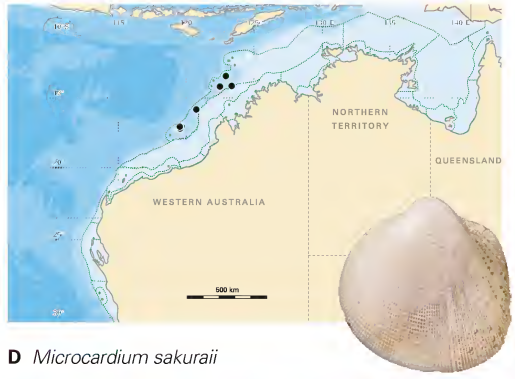
A *Frigidocardium eos*



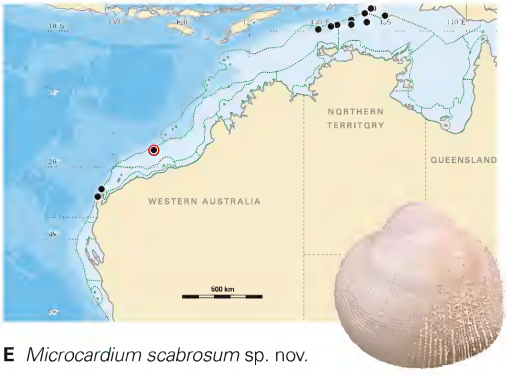
B *Frigidocardium iris*



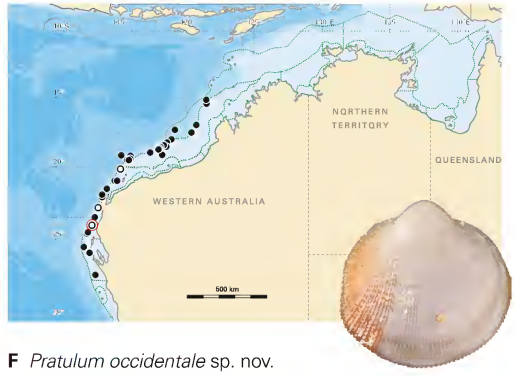
C *Frigidocardium torresi*



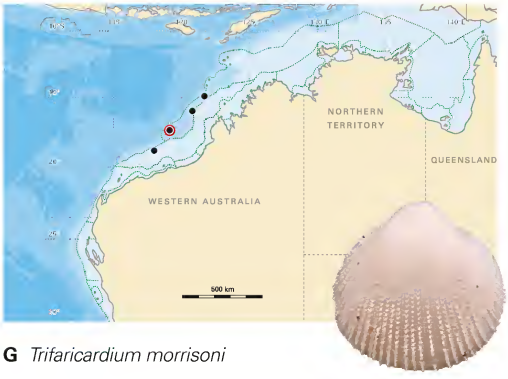
D *Microcardium sakuraii*



E *Microcardium scabrosum* sp. nov.

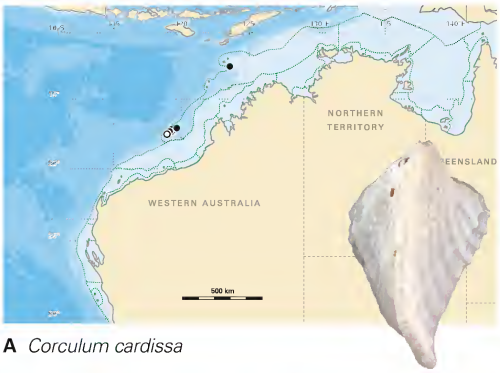


F *Pratulum occidentale* sp. nov.

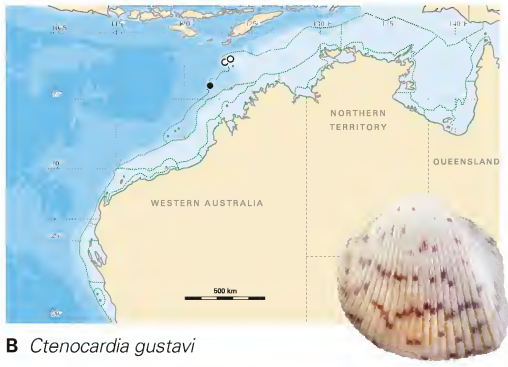


G *Trifaricardium morrisoni*

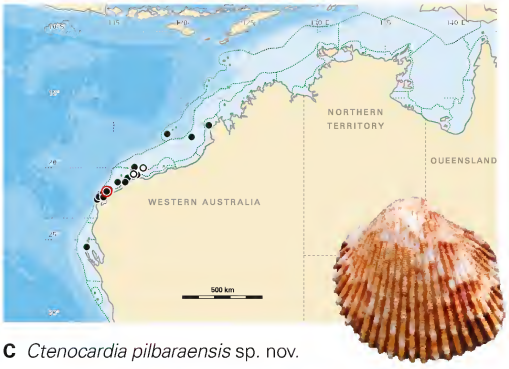
FIGURE 17 Recorded NW Australian distributions of *Frigidocardium*, *Microcardium*, *Pratulum* and *Trifaricardium* species treated in this paper for which at least three records could be established. Records are limited to the primary studied area (see Figure 1), with the inclusion of a single extralimital record of *Frigidocardium eos*. Dead records indicated by a black circle, live records indicated by a white circle, primary type records indicated by a red outline. Areas formed by the IMCRA coastal mesoscale bioregions (see Figure 1 for explanation) indicated by green dotted lines.



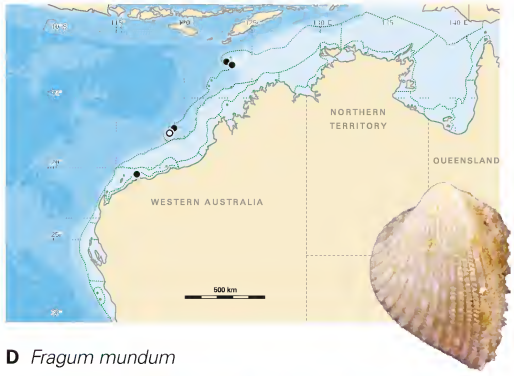
A *Corculum cardissa*



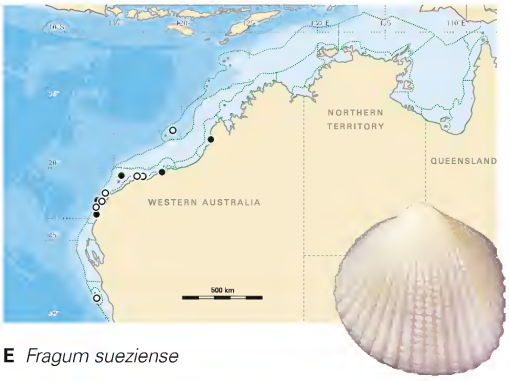
B *Ctenocardia gustavi*



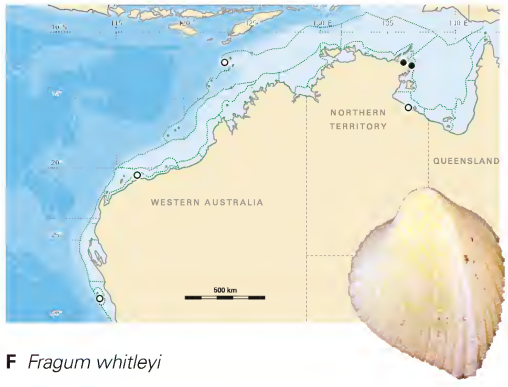
C *Ctenocardia pilbaraensis* sp. nov.



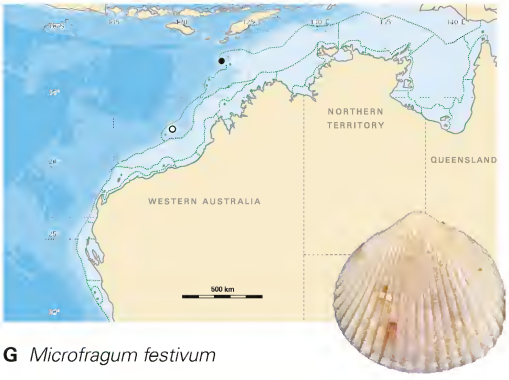
D *Fragum mundum*



E *Fragum sueziense*

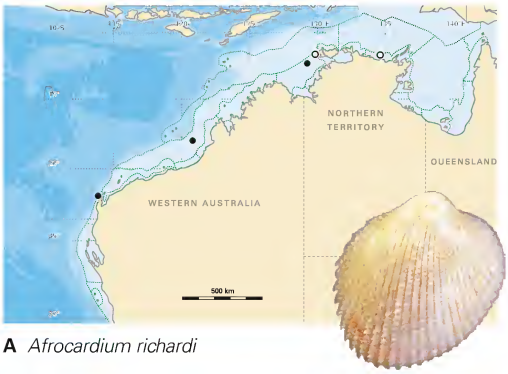


F *Fragum whitleyi*

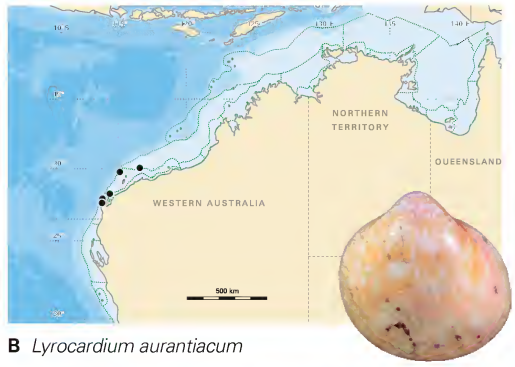


G *Microfragum festivum*

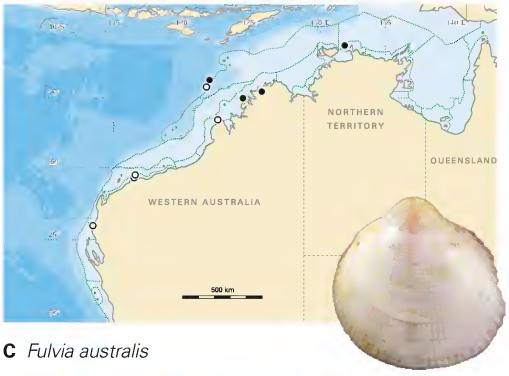
FIGURE 18 Recorded NW Australian distributions of *Corculum*, *Ctenocardia*, *Fragum* and *Microfragum* species treated in this paper for which at least three records could be established. Records are limited to the primary studied area (see Figure 1). Dead records indicated by a black circle, live records indicated by a white circle, primary type records indicated by a red outline. Areas formed by the IMCRA coastal mesoscale bioregions (see Figure 1 for explanation) indicated by green dotted lines.



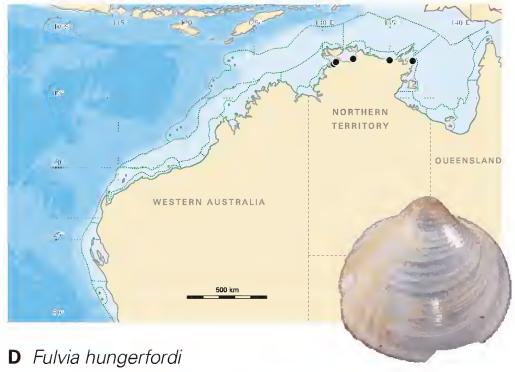
A *Afrocardium richardi*



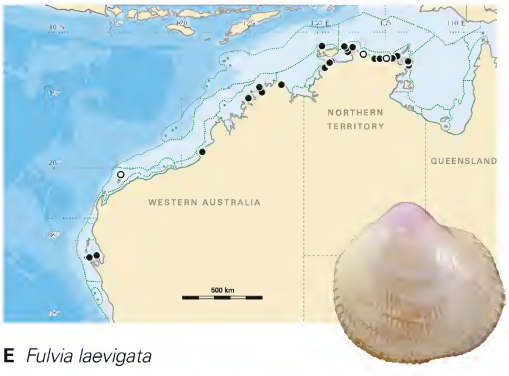
B *Lyrocardium aurantiacum*



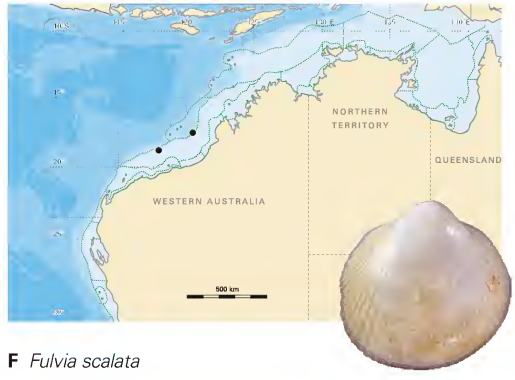
C *Fulvia australis*



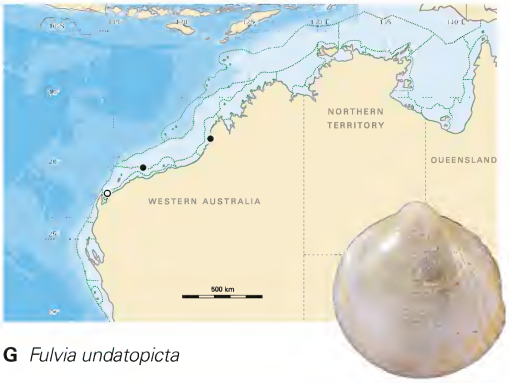
D *Fulvia hungerfordi*



E *Fulvia laevigata*

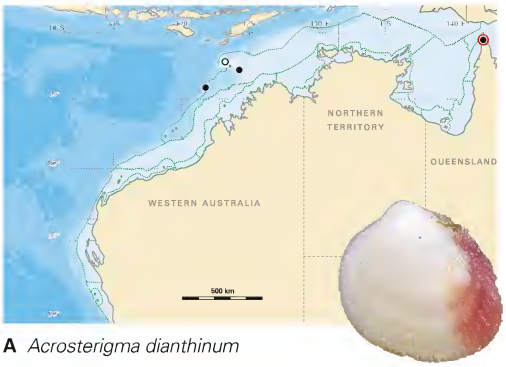


F *Fulvia scalata*

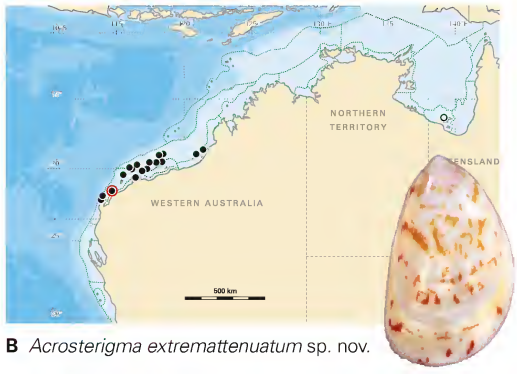


G *Fulvia undatopicta*

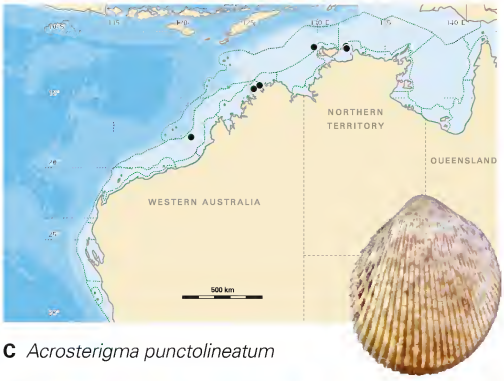
FIGURE 19 Recorded NW Australian distributions of *Afrocardium*, *Lyrocardium*, and *Fulvia* species treated in this paper for which at least three records could be established. Records are limited to the primary studied area (see Figure 1). Dead records indicated by a black circle, live records indicated by a white circle, primary type records indicated by a red outline. Areas formed by the IMCRA coastal mesoscale bioregions (see Figure 1 for explanation) indicated by green dotted lines.



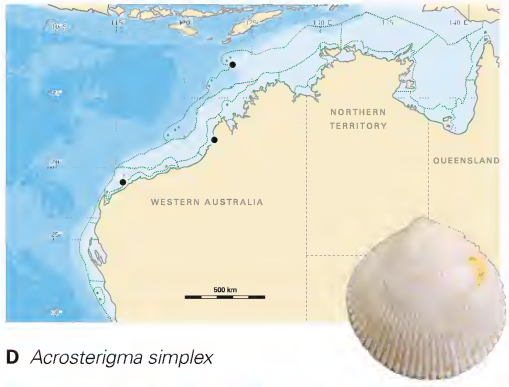
A *Acrosterigma dianthinum*



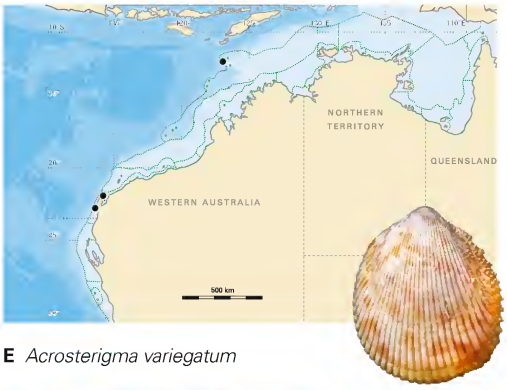
B *Acrosterigma extremattenuatum* sp. nov.



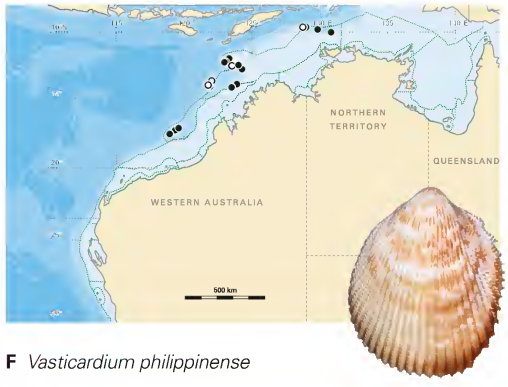
C *Acrosterigma punctolineatum*



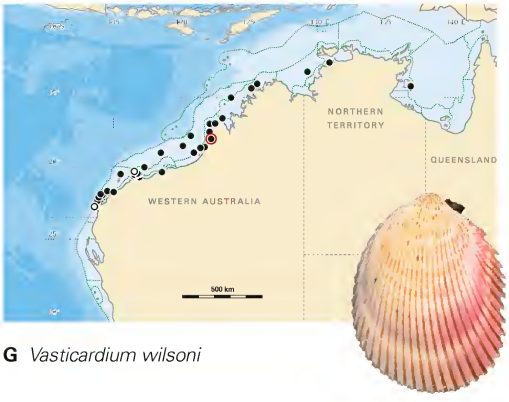
D *Acrosterigma simplex*



E *Acrosterigma variegatum*



F *Vasticardium philippinense*



G *Vasticardium wilsoni*

FIGURE 20 Recorded NW Australian distributions of *Acrosterigma* and *Vasticardium* species treated in this paper for which at least three records could be established. Records are limited to the primary studied area (see Figure 1). Dead records indicated by a black circle, live records indicated by a white circle, primary type records indicated by a red outline. Areas formed by the IMCRA coastal mesoscale bioregions (see Figure 1 for explanation) indicated by green dotted lines.

DISCUSSION

BIODIVERSITY AND TAXONOMY OF WA CARDIIDAE

The fauna of the northern offshore reefs was hardly known until a series of surveys were undertaken starting in the late 1970s-early 1980s (Berry and Marsh 1986; Morrison and Wells 2005), with the Montebello Islands only sporadically surveyed before 1993 (Wells and Berry 2000). Hence, Wilson and Stevenson (1977) had to base their data almost exclusively on the cardiids of inshore WA, with only one record from the Rowley Shoals and none from the Montebellos. In contrast, the Indonesian Roti Island (located only 145 km North of Ashmore Reef and separated by the Timor Trough) as well as neighbouring islands, had been visited by the Dutch Siboga Expedition as early as 1900 (Weber-van Bosse 1904). Given this sampling bias, Wilson and Stevenson (1977) nevertheless recognised 31 WA Cardiidae species of which 29 are considered valid today (Table 1). Targeted expeditions to the northern offshore reefs in intervening years have greatly improved diversity estimates at these rich IWP sites, with the number of widespread cardiid species increased from 23 to 52 (and nearly all extending only to the northern part of WA) (Figure 21). The same is true for the endemic WA species (from 3 to 6). In contrast, the number of endemic southern Australian species has remained unchanged (3) and was recorded previously (by Allan (1950) and Cotton (1961) for *Acrosterigma cygnorum* (Deshayes, 1855), *Fulvia tenuicostata* (Lamarck, 1819) and *Pratulum thetidis* (Hedley, 1902)).

Cardiids appear to be more highly concentrated in the IWP than most bivalve families. While Huber (2010: 40) mentions an IWP concentration of about 40% for known bivalve species, in cardiids, and following a much larger percentage of newly described species available from the IWP since 1975, the IWP portion has risen from 45% (1975) to 55% (2016, including the results of the present study) (Figures 22–23). With a significant number of WA cardiids peripherally distributed to the northern offshore reefs (Table 4, Figures 17–20, 24–25) or only rarely recorded from coastal waters, these offshore records are biogeographically of great importance in terms of adding to the species richness of Western Australia. The growing distinction between inshore and offshore macromolluscan faunal signatures was well demonstrated by Wells and Slack-Smith (1986), who added 70 species that were new records for WA (of which three were cardiids, viz. *Corculum cardissa, Tridacna* (*Chametrachea*) *crocea* and *Tridacna* (*Tridacna*) *gigas*), based on surveys to the northern offshore reefs. The number of new records was later increased to 121 molluscan species (Wells 1993; no additional cardiids), based on an additional survey of Ashmore Reef and Cartier Island. Altogether, over

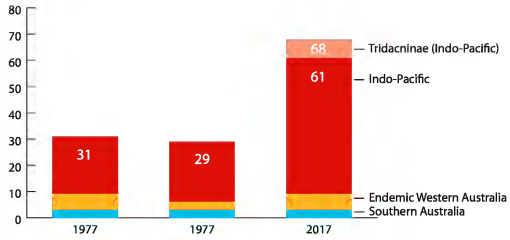


FIGURE 21 Stacked bar graph showing number of valid WA Cardiidae species in 1977 as recognised by Wilson and Stevenson (1977) (left); number of species in 1977 as currently considered valid (middle) and number of species in 2017 (right; Tridacninae indicated in pink), subdivided in three distributional regions.

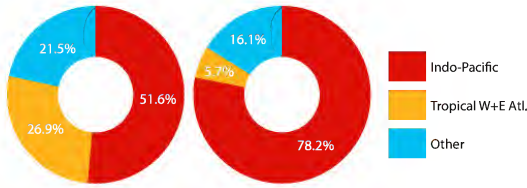


FIGURE 22 Biogeographical source of the new species of marine molluscs described in 2000-2014 (left, n = 6656; source: Bouchet et al. 2016) in comparison with the new Cardiidae species described in 1976-2016 (right, n = 87, Lymnocardiinae, Tridacninae and results of present study included; source: WoRMS (2016), supplemented with unpublished data). Indo-Pacific: red; tropical West and East Atlantic: orange; other fauna provinces: blue.

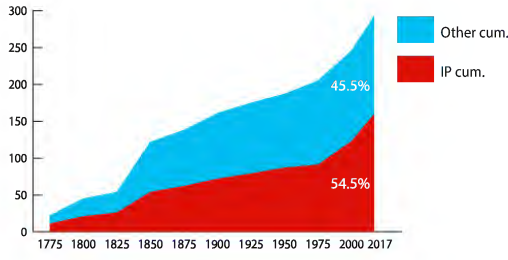


FIGURE 23 Accumulation curve of currently considered valid Cardiidae species described in 1758-2017 (∑ = 292, Lymnocardiinae, Tridacninae and results of present study included). Indo-Pacific (red, ∑ = 159), other fauna provinces (blue, ∑ = 133). Source: WoRMS (2016), supplemented with unpublished data.

20% of the molluscs collected on surveys of these atolls proved to be new records for WA (Wells et al. 2000). Surveys to the northernmost reefs carried out by Willan (2005) also yielded a new species record of a large bodied cardiid (*Vasticardium mindanense*) and quite recently, Bryce and Whisson (2009) added another tridacnine to the WA fauna, viz. *Tridacna* (*Tridacna*) *derasa*, found on Mermaid, Scott and Seringapatam Reefs. There is still more to explore with many offshore areas still unsurveyed. For example, the fauna of Fantome Bank, Karmt Shoal, Loxton Shoal, Sunset Shoal and Troubadour Shoals in the far northeast has still hardly been explored. The recent find of a large *Vasticardium sewelli* specimen (Figures 16A–D) from this area, known only from QLD (ter Poorten 1997) previously, demonstrates the need for additional sampling programs. More broadly, a focus on these areas will help to resolve the connectivity across the North and highlight how these submerged islands function as stepping stones between the top of Australia and the Coral Triangle.

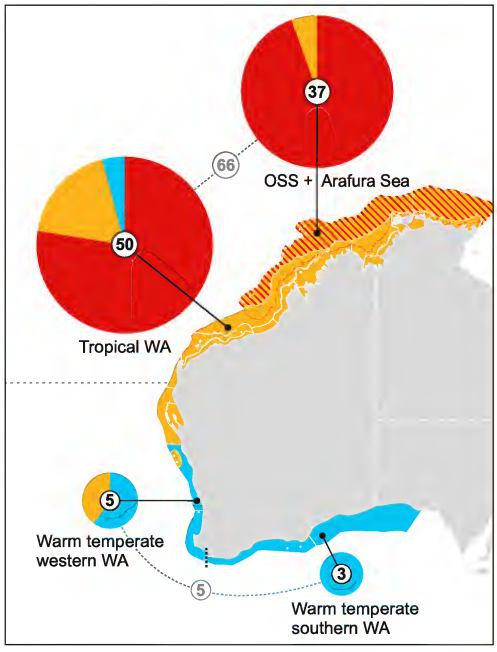


FIGURE 24 Pie charts showing zoogeographical composition and diversity of the WA cardiid molluscan fauna and adjacent areas (subdivided in four ecoregions, based on IMCRA bioregions). Number of species for each ecoregion indicated in circles.

Much new research on taxonomy and systematics has occurred on the cardiids since the work by Wilson and Stevenson (1977) forty years ago. One of the most significant developments and one that has greatly altered our understanding of higher level relationships has been the advent of molecular methods. In terms of the cardiids (Kirkendale 2009, Herrera et al. 2015), such approaches have reinforced the inclusion of the Tridacninae in the Cardiidae, but have also led to less certainty in other branches of the cardiid tree. For example, Herrera et al. (2015) demonstrated that Laevicardiinae was polyphyletic, with *Frigidocardium*, *Microcardium* and *Trifaricardium* distributed in a clade basal to all other living cardiids; and that Laevicardiinae is sister to Trachycardiinae, both forming the youngest lineages of the family.

ENDEMISM IN WESTERN AUSTRALIAN CARDIIDS

Sixteen cardiids occurring on the northern offshore reefs (OSS bioregion) are not known from the continental mainland of WA, resulting in a rather low level of similarity (32%) between inshore and offshore areas (Figure 26, Appendix). All endemic WA cardiids are restricted to coastal or inshore WA, none of them are recorded from the offshore reefs (Table 4, Figure 24); a pattern that holds for molluscs in general (Wells 2002). Not unexpectedly, the northern offshore reef fauna is an extension of a large central IWP distribution rather than an Indian Ocean provenance — also in line with that of molluscs in general, given the present inter-oceanic currents (Hoeksema 2007). The influence of the Indonesian Throughflow (ITF, Figure 1), which supplies the North West Shelf with tropical water from the western Pacific via southeastern Indonesian island corridors (Wilson 2013) has a critical role in distributing planktonic larvae via the seasonal Holloway Current (Wilson 2014) into the Indian Ocean. The phylogeographic observation that much of the eastern Indian Ocean fauna exhibits genetic affinity with the Pacific and not with the Indian Ocean fauna has been recently proposed to be called 'the Leeuwin effect' (Wilson and Kirkendale 2016).

Oceanographic and geographic processes thus drive the higher level of similarity observed in the cardiid fauna of Central/East Indonesia and the northern offshore reefs of WA (41%), than between inshore and offshore WA (32% as reported above) (Figure 26, Appendix). Likewise, all non-endemic WA cardiids also occur in Indonesia and/or the Philippines (Table 4, Appendix) and none of them has an exclusively Indian Ocean distribution, again reflecting the general molluscan pattern (Wilson 2013). In fact, the same pattern holds for the cardiids of the AIOT (Christmas Island and Cocos (Keeling) Islands, Table 3), which exhibit a rate of endemism for molluscan species of less than 4% (Tan and Low 2014). With a level of endemism of approximately 75% (Huber 2010) or even up to 95% (Wilson and Allen 1987; Ponder et al. 2002), it is unsurprising that the cardiid level of similarity between northern WA and southern WA is only 3%

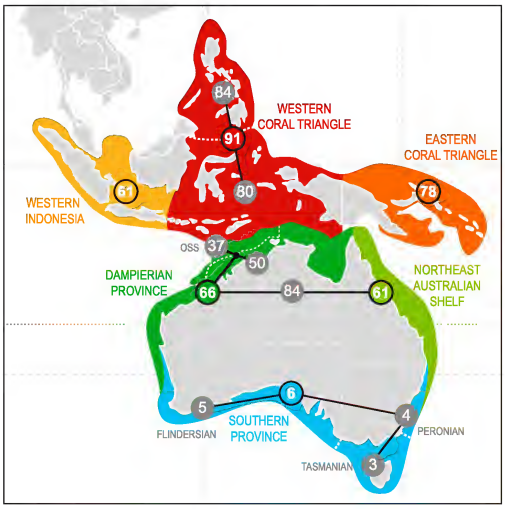


FIGURE 25 Cardiidae diversity in Central IWP and Australia (verified records; Tridacninae included). Number of species in coloured circles; number of subareas and combined areas in white/gray circles.

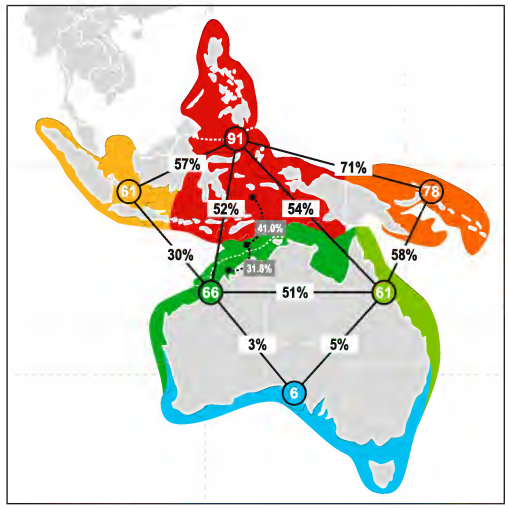


FIGURE 26 Cardiidae levels of similarity in Central IWP and Australia (verified records; Tridacninae included). Number of species in circles.

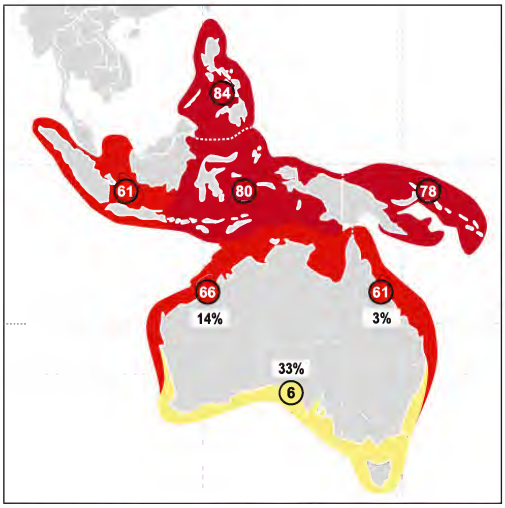


FIGURE 27 Cardiidae diversity in Central IWP and Australia (verified records; Tridacninae included). Number of species in circles. Endemism in Dampierian Province, Solanderian Province and southern Australia in %.

FIGURE 28 Coral diversity in Central IWP ecoregions indicated by all records of occurrences (after Veron et al. 2015: fig. 4).

(Figure 26, Appendix). Just as in corals (Veron et al. 2015; Figure 28), cardiids of high latitude ecoregions have less similarity with their nearest neighbour than do cardiids in tropical ecoregions (Figure 26). All of these observations corrorborate that tropical WA *Pratulum* records relate to a different species (*P. occidentale* sp. nov.), and we confirm here that *P. thetidis* (Hedley, 1902) is an endemic South Australian species, confined to temperate waters in WA and only marginally occurring in deeper waters off southern QLD.

BIODIVERSITY AND BIOGEOGRAPHY ACROSS NORTHERN AUSTRALIAN

The 25 species comprising the cardiid fauna of the NT (Table 4) (including 4 Tridacninae; none endemic to NT) is much less diverse than that of WA. Large parts of the coasts are dominated by river estuaries and mangrove systems; the development of coral reefs is limited and offshore emergent reefs are lacking. Hence, habitat heterogeneity is more restricted compared to WA. The Joseph Bonaparte Gulf, with its large river systems contributing a lot of silt and freshwater (enhanced by the heavy rainfall in the monsoon season), acts as a barrier, preventing the majority of WA cardiids from crossing the NT border (personal communication R. Willan, 2014). Whereas the northern offshore reefs lie directly in the path of the ITF, this cannot be said for the NT, which is largely lacking these kinds of conduits for dispersal. Connectivity between the Coral Sea and the Arafura Sea has been impeded by a very wide land bridge that fully connected the NT with New Guinea, the Torres Strait remaining closed until 6,000 years BP (Wilson 2013: 315, fig. 2.12). Currently, the narrow and shallow Torres Strait (with the Torres Sill only 12 m deep) still forms a biogeographic barrier, hampering dispersal of molluscan larvae. Not unexpectedly, the only NT cardiid absent from WA has a marked preference for shallow muddy environments: *Fulvia hungerfordi* (G.B. Sowerby III, 1901) (Table 4; ter Poorten 2009). Common, widespread shallow water species that prefer clean sand in coral reef environments, like *Fragum fragum* (Linnaeus, 1758), *Microfragum festivum* (Deshayes, 1855) and *Hippopus hippopus* (Linnaeus, 1758), are altogether lacking in the NT. *Tridacna* species have not been reported from the more turbid and sheltered inshore areas with limited coral growth like the Van Diemen and Beagle Gulfs. Deep water species, like *Freneixicardia victor* (Angas, 1872), represented in WA by 18 specimens, have not been recorded from the NT (although the scarcity of deeper water biota may be explained by undersampling, not by true absence). Altogether, collecting effort and intensity has been much lower and has been strongly focussed on the Darwin area.

A number of biogeographic provinces in the IWP region have been proposed and some are quite different from one another. While Briggs and Bowen (2012) call for recognition of a vast Indo-Polynesian province, extending from the Arabian Gulf in the Indian ocean to the Tuamotu Archipelago (Polynesia) in the central Pacific Ocean, others recognise increasing levels of structure, such as a number of provinces within the Indo-Polynesian province (Kulbicki et al. 2013) and even Wilson (2013: 9, fig. 1.3) presents a northwestern and northeastern province. However, Wilson (2013) finishes with a strong case for recognition of further biogeographical distinction, specifically a Dampierian Province (p. 392–393) with one of the major aims of his study to consider whether the North West Shelf meets the criteria for designation as a distinctive province within the Northern Australian Subrealm (Wilson 2013: 7). A number of criteria (e.g. geomorphological, climatic, geological) and faunal elements (e.g. also corals, fish, and consideration of levels of endemicity and dissimilarity with other adjacent regions) are considered. Wilson (2013: 391, table 9.1) finds an overall species endemicity of 12% (in three families that have planktotrophic larvae: Mytilidae, Cardiidae and Strombidae) or 19% (Cardiidae only) for the area covering the North West Shelf, Arafura Sea, and Gulf of Carpentaria. With the new taxonomy, biodiversity assessments and distributional data presented here for the cardiids, we support a Dampierian Province. Our composite data indicate 14% endemism (Figure 27, Appendix) and strikingly, all four of the new species described herein represent Dampierian endemics, further attesting to the veracity of this signature. While this level of endemism is not as high as found in the cardiids of temperate southern Australia (Flindersian + Tasmanian + Peronian = 33%), it is more than that found for the neighboring Solanderian (3%, *Vasticardium serricostatum* and the undescribed *Trifaricardium* sp. the only endemics). The contrast between the neighboring Damperian and Solanderian Provinces is striking in the cardiids and can be explained by the Solanderian Province exhibiting higher levels of similarity with adjacent areas (e.g. 58% similarity with the Eastern Coral Triangle), such that while the area is rich it is not overly endemic, instead comprised of a number of IWP species (e.g. Table 5, Figures 25, 26). Why the Dampierian is not swamped by IWP species like the Solanderian but instead has developed and retained a stronger endemic signature is the result of many factors (Wilson 2013). Sea level changes and variable current intensity from the north have resulted in unreliable connectivity among populations that may have promoted opportunities for *in situ* speciation over geological timescales. This coupled with the novel environmental conditions layered across a diversity of microhabitats are certainly important additional drivers in northern WA.

Intensified collection research, combined with increased sampling in the central IWP and the continental shelf off north-western Australia, has greatly enhanced our understanding and broader affinities of the WA cardiid fauna in the past 40 years. A critical review of museum specimens and literature has increased the number of recorded WA Cardiidae species from 29 to 61

(68 including Tridacninae). In this study, no less than 16 species are reported for the first time from WA, all but one having a wide central IWP range. It is this central IWP component of the WA fauna that was still poorly known in 1977, resulting in a more than doubling of the species number (from 23 to 52). In sharp contrast, the number of Southern Australian species (3) has remained constant (Figures 21, 24). With the vast majority of the additional species being peripherally distributed off the northern coast of WA, and our knowledge of the IWP fauna still far from complete, it is suggested that the IWP component will prove to be of even more importance in the future, resulting in an even steeper latitudinal gradient along the WA coastline (Figures 22–25).

The strong increase of northern WA cardiids is in line with findings that northern Australia forms a distinct diversity 'bulge' (or hotspot) in the southern hemisphere (Crame 2000, Hoeksema 2017). The cardiid diversity of north-western Australia approaches that of Central Indonesia, and except for the four new species, all species added to the WA fauna by this study and Willan et al. (2015), (19 in total) were already known from Indonesia. It appears that regional environmental factors override latitudinal diversity gradient effects, as is argued for northern WA by Wilson (2013). Some cardiids are clearly restricted to the northern WA offshore reefs, which probably have acted as important stepping stones for further colonisation along the WA continental coasts, especially during extraordinary oceanographic events like cyclonic storms. Taking into account mode of development and habitat preferences, there is no reason to believe that the described shifts in the composition of the WA distribution patterns are unique for cardiids. Although certainly improved and indicative, estimates of IWP cardiid diversity are still heavily biased by collecting intensity and are not yet an actual account of the true biodiversity.

Based on the available data for cardiids, the northern Australian diversity approximately equals that of the hyperdiverse Indonesia and Philippines, an outcome already reported for prosobranch gastropods (Wells 1990), but less apparent for corals (Veron et al. 2015; Figures 25–26). At present, the total WA Cardiidae fauna totals 68 species (Table 4), three of which are endemic to South Australia, which leaves 65 species in the tropics. With the addition of the 18 QLD species that do not occur in WA (Table 5), plus *Pratulum thetidis*, a total of 84 Cardiidae species occur in the tropical northern part of Australia (Figures 23, 25). Philippine diversity is quite well documented (ter Poorten 2009, 2011; unpubl. data) and totals 84 species, while Indonesian diversity was discussed by ter Poorten (2007; unpubl. data) and equals 86 species. The combined Indonesian-Philippine cardiid fauna is 98 species, whereas the combined Indonesian-tropical WA and northern offshore reefs fauna is 99 species (Appendix). These numbers, as well as extrapolations to larger groups should be treated with caution, given the possibility of sampling bias (e.g. overrepresentation of macromolluscs or undersampling of certain regions). However, a sampling bias is also apparent in the WA cardiid fauna, with no specialist methods employed to target cryptic, micromollusc or deep sea habitats until relatively recently (in contrast, specialist methods have been employed in other surveys for decades within the Coral Triangle). Thus the WA cardiid fauna, although underrepresented given a lack of specialist methods and attention, still manages to achieve a biodiversity 'score' on a par with the richest regions in the world. This finding has been recently revisited by Hoeksema (2017) who argued that the boundaries of the central IWP diversity centre are contested and unlikely to be triangular, again calling for a renaming of this area to Indo-Australian Archipelago, to recognise in part the high diversity emerging from Australia (Hoeksema 2007). It also reinforces the notion of Wilson (2013: 269) who argued that viewing the Arafura and Sahul Shelves as part of the East Indies Triangle (approximately coinciding with and recently referred to as the Coral Triangle), or at least an extension of it, is justified, based on the magnitude, affinity, and proximity of the marine biota.

CLOSING THE GAP IN WESTERN AUSTRALIA

The work by Wilson and Stevenson (1977) was significant as it was one of the first regional treatments of a well known, widespread and conspicuous group in WA. However, taxonomic work on cardiids in WA was not revisited as the WAM collections grew. This lack of expert scrutiny, which can be termed an 'expert bias', has been one issue that has seriously hampered the resolution of distribution patterns and composition of the WA cardiid fauna. While the work presented here redresses this 'expert bias', and identifies material in the WAM collections, it seems likely that the real richness of the WA cardiid fauna is still underestimated. This is largely because much of the WA expedition work has been a 'Rapid Assessment' style that must function across many phyla, with modest sampling efforts (typically approximately 15 to 50 day-persons — Slack-Smith and Bryce 2004: table 1; Bryce and Whisson 2009: table 5) often constrained by extreme environmental conditions (tides, visibility, etc.). This sampling bias in WA cardiids has been made apparent largely due to the recent large scale marine expeditions undertaken to neighbouring countries such as New Caledonia (Bouchet et al. 2002), Vanuatu (Bouchet et al. 2008) and the Philippines (Bouchet 2009) by MNHN. These mollusc and crustacea focused initiatives typically deploy people power of 400 up to 2,000 day-persons and a suite of collecting techniques like scuba-operated vacuum cleaners and newly developed 'brushing baskets'. These methods, coupled with taxonomic expertise necessary to document the fauna in real time, have led to impressive species lists for hyperdiverse areas of the IWP, including cardiids (Vidal 1999, ter Poorten 2009, 2012, 2013, 2015); such work is rapidly improving our knowledge of hidden corners (deep sea, reef matrices) and dark taxa (e.g. cryptic species, small-bodied taxa) (Page 2016).

Progress is apparent in WA where new light is being shone on these hidden corners and dark taxa. The highly speciose micromolluscan fauna, also containing small and juvenile cardiid species (Wilson 2013), is under study after a long period of inactivity. Approximately 60 stations in the marine area adjacent to the Kimberley (including sites from as far north as Ashmore/Hibernia and as far west as Rowley Shoals) have been sampled for micromolluscs and a subsample of this material has been sorted, photo-documented, registered and identified to morphospecies (Middelfart, unpublished/in preparation, Middelfart et al. 2016). Analysis of these samples is underway and will begin to reveal the presence of small and juvenile cardiids, with a planned expansion of the program to other areas in WA. Like micromolluscs, which are a faunal gap worldwide, the deep sea is a regional gap in WA and poorly known compared to shallow coastal seas. Although the deep water fauna has received little attention in WA (Ponder et al. 2002: Table 3.1), the Southern Surveyor expedition was significant in sampling 123 deep sites from the north to the south of the state, with molluscs deposited in the WAM collections. This expedition improved ranges for several deep water cardiid taxa, provided important material for the description of *Pratulum occidentale* sp. nov., and the first Australian record of *Acrosterigma suduirauti* Vidal & ter Poorten, 2007.

FUTURE GOALS

Cardiids offer the opportunity to pose the big questions in evolutionary ecology and historical biogeography, given their presence in most ocean basins across a variety of habitats, an excellent fossil record and moderate biodiversity. However, these downstream pursuits fundamentally rely on taxonomy, which beyond nomenclature provide our most accurate understanding of diversity and distribution (Jablonski et al. 2017). In relation to the cardiids, we have certainly made headway in tackling the problem highlighted by Roberts and Wells (1980: 335) that stated the 'marine and estuarine molluscs of the State [WA] are very poorly known'. However, we are still a long way from meeting the challenge recently documented by Willan et al. (2015), with the expectation of 5,000 molluscs in WA, of which we have only documented 1,784 (less than half). Interestingly, a century ago, Hedley (1916: 152) predicted that 'the number [of WA molluscs] will be increased perhaps fourfold when small species and those from deep water are collected.' His species list only contained 14 WA cardiid species. Biodiversity surveys utilizing modern methods aligned with other international surveys to facilitate comparisons need government and industry support. This will enable research teams to continue to reveal the rich biodiversity of local areas, while providing accurate biogeographic assessments to enable broader regional comparisons, all necessary to inform best practise conservation measures (e.g. the placement of Marine Protected Areas or MPAs) at multiple governmental scales (Wilson 2016). While cardiids are relatively popular and well studied, and could be thought of as 'charismatic megafauna' of the molluscan world, many other groups are much more poorly known. The need for collaborations by international taxonomic experts and programs to train the next generation of biodiversity 'hotspotters' to tackle poorly known molluscan groups in Australia, is a massive future frontier.

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APPENDIX Cardiidae distributions for the Dampierian Province, Northeast Australian Shelf (Solanderian), Southern Australia, Western Indonesia, Western Coral Triangle and Eastern Coral Triangle, corresponding with the areas given in Figure 25. 1 = present, 0 = absent. Data based on verified samples, except for few occurrences in grey, that are based on literature data, Numbers in bold type refer to endemic DMP, SOL and SA species.

DMP = Damperian, NOR = Northern offshore reefs, SOL = Solanderian, FLN = Flindersian, TAS = Tasmanian, PER = Peronian, SA = South Australia (Flindersian + Tasmanian + Peronian), WI = West Indonesia, CEI = Central East Indonesia, PHI = Philippines, WCT = West Coral Traingle, ECT = East Coral Triangle, OSS = Oceanic Shoals, IMCRA = Integrated Marine and Coastal Regionalisation of Australia.

An extended version of the Appendix, containing similarity calculations and sources is available as a Supplementary data file and can be downloaded from here: http://dx.doi.org/10.18195/issn.0312-3162.32(2).2017.101-190

Species	DMP (total)	DMP (excl. OSS)	NOR (=OSS, IMCRA)	SOL	FLN	TAS	PER	SA	WI	CEI	PHI	WCT	ECT	Distribution
'*Laevicardium' lobulatum* (Deshayes, 1855)	1	0	1	1	0	0	0	0	1	1	1	1	1	IWP
Acrosterigma attenuatum (G.B. Sowerby II, 1841)	0	0	0	1	0	0	0	0	1	1	1	1	1	IWP
Acrosterigma biradiatum (Bruguière, 1789)	1	1	1	1	0	0	0	0	1	1	1	1	1	IWP
Acrosterigma cygnorum (Deshayes, 1855)	0	0	0	0	1	1	1	**1**	0	0	0	0	0	S.A.
Acrosterigma dianthinum (Melvill & Standen, 1899)	1	0	1	1	0	0	0	0	0	1	1	1	1	IWP
Acrosterigma extremattenuatum sp. nov.	**1**	1	0	0	0	0	0	0	0	0	0	0	0	N.Austr.
Acrosterigma hobbsae Vidal, 1999	0	0	0	1	0	0	0	0	1	1	1	1	1	IWP
Acrosterigma impolitum (G.B. Sowerby II, 1834)	1	1	0	1	0	0	0	0	1	1	1	1	1	IWP
Acrosterigma kerslakae Healy & Lamprell, 1992	0	0	0	1	0	0	1	1	0	0	0	0	0	E.Austr.
Acrosterigma maculosum (W. Wood, 1815)	0	0	0	1	0	0	0	0	1	1	1	1	1	IWP
Acrosterigma marielae Wilson & Stevenson, 1977	1	1	0	0	1	0	0	1	0	0	0	0	0	WA
Acrosterigma sp. nov. 1	0	0	0	0	0	0	0	0	1	0	0	0	0	IWP
Acrosterigma sp. nov. 2	0	0	0	0	0	0	0	0	0	0	1	1	0	IWP
Acrosterigma sp. nov. 3	0	0	0	0	0	0	0	0	0	0	0	0	1	IWP
Acrosterigma profundum Vidal, 1999	0	0	0	0	0	0	0	0	0	0	0	0	1	IWP
Acrosterigma punctolineatum Healy & Lamprell, 1992	1	1	0	1	0	0	0	0	1	1	1	1	1	IWP
Acrosterigma simplex (Spengler, 1799)	1	1	1	1	0	0	0	0	1	1	1	1	1	IWP
Acrosterigma suduirauti Vidal & ter Poorten, 2007	1	0	1	0	0	0	0	0	0	1	1	1	0	IWP
Acrosterigma suluanum Vidal, 1999	0	0	0	0	0	0	0	0	0	0	1	1	0	IWP
Acrosterigma transcendens (Melvill & Standen, 1899)	1	1	1	1	0	0	0	0	1	1	1	1	1	IWP
Acrosterigma uniornatum Vidal, 1999	0	0	0	0	0	0	0	0	0	0	0	0	1	IWP
Acrosterigma variegatum (G.B. Sowerby II, 1840)	1	1	1	1	0	0	0	0	1	1	1	1	1	IWP
Afrocardium exochum (Melvill & Standen, 1907)	0	0	0	1	0	0	0	0	1	1	1	1	1	IWP
Afrocardium richardi (Audouin, 1826)	1	1	0	1	0	0	0	0	1	1	1	1	1	IWP
Corculum cardissa (Linnaeus, 1758)	1	0	1	1	0	0	0	0	1	1	1	1	1	IWP
Ctenocardia fornicata (G.B. Sowerby II, 1840)	1	0	1	1	0	0	0	0	1	1	1	1	1	IWP

Species	DMP (total)	DMP (excl. OSS)	NOR (=OSS, IMCRA)	SOL	FLN	TAS	PER	SA	WI	CEI	PHI	WCT	ECT	Distribution
Ctenocardia gustavi Vidal & Kirkendale, 2007	1	0	1	0	0	0	0	0	1	1	1	1	1	IWP
Ctenocardia pilbaraensis sp. nov.	**1**	1	1	0	0	0	0	0	0	0	0	0	0	IWP
Ctenocardia translata (Prashad, 1932)	0	0	0	0	0	0	0	0	1	1	1	1	1	IWP
Ctenocardia virgo (Reeve, 1845)	1	1	0	1	0	0	0	0	1	1	1	1	1	IWP
Discors multipunctatum (G.B. Sowerby I, 1833)	0	0	0	0	0	0	0	0	1	1	1	1	1	IWP
Fragum erugatum (Tate, 1889)	1	1	0	1	0	0	0	0	0	0	1	1	0	IWP
Fragum fragum (Linnaeus, 1758)	1	1	1	1	0	0	0	0	1	1	1	1	1	IWP
Fragum grasi ter Poorten, 2009	0	0	0	0	0	0	0	0	1	1	1	1	1	IWP
Fragum mundum (Reeve, 1845)	1	1	1	1	0	0	0	0	0	1	1	1	1	IWP
Fragum vanuatuense ter Poorten, 2015	0	0	0	1	0	0	0	0	0	1	1	1	1	IWP
Fragum sp. aff. *scruposum* (Deshayes, 1855)	1	1	0	0	0	0	0	0	0	1	0	0	1	IWP
Fragum sueziense (Issel, 1869)	1	1	1	1	0	0	0	0	1	1	1	1	1	IWP
Fragum unedo (Linnaeus, 1758)	1	1	1	1	0	0	0	0	1	1	1	1	1	IWP
Fragum whitleyi Iredale, 1929	1	1	1	1	0	0	0	0	1	1	1	1	1	IWP
Freneixicardia victor (Angas, 1872)	1	1	0	1	0	0	0	0	0	1	1	1	1	IWP
Frigidocardium eos (Kuroda, 1929)	1	1	1	0	0	0	0	0	0	1	1	1	1	IWP
Frigidocardium helios ter Poorten & Poutiers, 2009	1	1	0	0	0	0	0	0	1	1	1	1	1	IWP
Frigidocardium iris Huber & ter Poorten, 2007	1	1	1	0	0	0	0	0	0	1	1	1	0	IWP
Frigidocardium kiranum Sakurai & Habe, 1966	0	0	0	0	0	0	0	0	0	1	1	1	0	IWP
Frigidocardium sp. nov. 1	0	0	0	1	0	0	0	0	0	1	1	1	1	IWP
Frigidocardium sancticaroli ter Poorten & Poutiers, 2009	0	0	0	0	0	0	0	0	0	1	1	1	1	IWP
Frigidocardium torresi (E.A. Smith, 1855)	1	1	1	0	0	0	0	0	1	1	1	1	1	IWP
Fulvia aperta (Bruguière, 1789)	1	1	1	1	0	0	0	0	1	1	1	1	1	IWP
Fulvia australis (G.B. Sowerby II, 1834)	1	1	1	1	0	0	0	0	1	1	1	1	1	IWP
Fulvia boholensis Vidal, 1994	1	1	0	0	0	0	0	0	0	1	1	1	0	IWP
Fulvia colorata Vidal & Kirkendale, 2007	0	0	0	0	0	0	0	0	0	1	1	1	1	IWP
Fulvia dulcis (Deshayes, 1863)	0	0	0	0	0	0	0	0	0	1	0	1	1	IWP
Fulvia fragiformis Vidal, 1994	0	0	0	1	0	0	0	0	0	0	0	0	1	WP
Fulvia hungerfordi (G.B. Sowerby III, 1901)	1	1	0	1	0	0	0	0	1	1	1	1	1	IWP
Fulvia laevigata (Linnaeus, 1758)	1	1	0	1	0	0	0	0	1	1	1	1	1	IWP
Fulvia lineonotata Vidal, 1994	0	0	0	0	0	0	0	0	0	1	1	1	1	IWP
Fulvia nienkeae ter Poorten, 2012	0	0	0	1	0	0	0	0	0	1	1	1	1	IWP
Fulvia scalata Vidal, 1994	1	1	0	1	0	0	0	0	1	1	1	1	1	IWP
Fulvia subquadrata Vidal & Kirkendale, 2007	0	0	0	0	0	0	0	0	0	0	1	1	1	IWP
Fulvia tenuicostata (Lamarck, 1819)	0	0	0	0	1	1	1	**1**	0	0	0	0	0	S.A.

Species	DMP (total)	DMP (excl. OSS)	NOR (=OSS, IMCRA)	SOL	FLN	TAS	PER	SA	WI	CEI	PHI	WCT	ECT	Distribution
Fulvia undatopicta (Pilsbry, 1904)	1	1	0	1	0	0	0	0	1	1	1	1	1	IWP
Hippopus hippopus (Linnaeus, 1758)	1	1	1	1	0	0	0	0	1	1	1	1	1	IWP
Hippopus porcellanus Rosewater, 1982	0	0	0	0	0	0	0	0	0	1	1	1	0	IWP
Lunulicardia auricula (Niebuhr in Forsskål, 1775)	0	0	0	1	0	0	0	0	0	0	0	0	1	IWP
Lunulicardia hemicardium (Linnaeus, 1758)	0	0	0	1	0	0	0	0	1	1	1	1	1	IWP
Lunulicardia retusa (Linnaeus, 1767)	1	1	0	1	0	0	0	0	1	1	1	1	0	IWP
Lunulicardia tumorifera (Lamarck, 1819)	**1**	1	0	0	0	0	0	0	0	0	0	0	0	WA
Lyrocardium aurantiacum (A. Adams & Reeve, 1850)	1	1	0	1	0	0	0	0	1	1	1	1	1	IWP
Lyrocardium lyratum (G.B. Sowerby II, 1840)	1	1	0	1	0	0	0	0	1	1	1	1	1	IWP
Maoricardium fraseri (Garrard, 1963)	1	1	0	1	0	0	0	0	0	0	0	0	0	N.Austr.
Maoricardium pseudolatum Voskuil & Onverwagt, 1991	0	0	0	1	0	0	0	0	1	1	1	1	1	IWP
Maoricardium setosum (Redfield, 1848)	1	1	0	1	0	0	0	0	1	1	1	1	0	IWP
Microcardium aequiliratum Poutiers, 1981	0	0	0	0	0	0	0	0	0	0	1	1	0	IWP
Microcardium sp. nov. 1	0	0	0	0	0	0	0	0	0	0	1	1	0	IWP
Microcardium sp. nov. 2	0	0	0	0	0	0	0	0	0	0	0	0	1	IWP
Microcardium sakuraii (Habe, 1961)	1	0	1	0	0	0	0	0	0	1	1	1	1	IWP
Microcardium scabrosum sp. nov.	**1**	1	1	0	0	0	0	0	0	1	0	1	0	N.Austr.
Microcardium tenuilamellosum Poutiers, 1981	0	0	0	0	0	0	0	0	0	0	1	1	1	IWP
Microcardium velatum ter Poorten & Poutiers, 2009	0	0	0	0	0	0	0	0	0	0	1	1	1	IWP
Microfragum festivum (Deshayes, 1855)	1	0	1	1	0	0	0	0	1	1	1	1	1	IWP
Microfragum subfestivum Vidal & Kirkendale, 2007	0	0	0	1	0	0	0	0	1	1	1	1	1	IWP
Nemocardium bechei (Reeve, 1847)	0	0	0	0	0	0	0	0	0	1	1	1	0	IWP
Nemocardium fulvum ter Poorten, 2013	0	0	0	0	0	0	0	0	0	1	1	1	0	IWP
Nemocardium probatum (Iredale, 1927)	1	1	0	1	0	0	0	0	0	0	0	0	0	N.Austr.
Pratulum occidentale sp. nov.	**1**	1	0	0	0	0	0	0	0	0	0	0	0	WA
Pratulum thetidis (Hedley, 1902)	0	0	0	1	1	1	1	1	0	0	0	0	0	S.A.
Pseudofulvia caledonica Vidal & Kirkendale, 2007	0	0	0	0	0	0	0	0	0	0	1	1	1	IWP
Tridacna (Chametrachea) crocea Lamarck, 1819	1	0	1	1	0	0	0	0	1	1	1	1	1	IWP
Tridacna (Chametrachea) maxima (Röding, 1798)	1	1	1	1	0	0	0	0	1	1	1	1	1	IWP
Tridacna (Chametrachea) noae (Röding, 1798)	1	1	0	0	0	0	0	0	0	1	1	1	1	IWP
Tridacna (Chametrachea) squamosa Lamarck, 1819	1	1	1	1	0	0	0	0	1	1	1	1	1	IWP
Tridacna (Tridacna) derasa (Röding, 1798)	1	0	1	1	0	0	0	0	1	1	1	1	1	IWP
Tridacna (Tridacna) gigas (Linnaeus, 1758)	1	0	1	1	0	0	0	0	1	1	1	1	1	IWP
Tridacna (Tridacna) mbalavuana Ladd, 1934	0	0	0	0	0	0	0	0	0	0	0	0	1	IWP
Trifaricardium morrisoni ter Poorten & Huber, 2007	**1**	1	1	0	0	0	0	0	0	0	0	0	0	WA

Species	DMP (total)	DMP (excl. OSS)	NOR (=OSS, IMCRA)	SOL	FLN	TAS	PER	SA	WI	CEI	PHI	WCT	ECT	Distribution
Trifaricardium sp. nov. 1 sensu Poutiers, 1992	0	0	0	**1**	0	0	0	0	0	0	0	0	0	E.Austr.
Trifaricardium nomurai Kuroda & Habe, 1951	1	0	1	0	0	0	0	0	0	0	1	1	1	IWP
Vasticardium angulatum (Lamarck, 1819)	1	1	1	1	0	0	0	0	1	1	1	1	1	IWP
Vasticardium berschaueri Thach, 2014	0	0	0	0	0	0	0	0	1	0	0	0	0	IWP
Vasticardium dupuchense (Reeve, 1845)	**1**	1	0	0	0	0	0	0	0	0	0	0	0	WA
Vasticardium elongatum (Bruguière, 1789)	1	0	1	0	0	0	0	0	1	1	1	1	0	IWP
Vasticardium enode (G.B. Sowerby II, 1840)	0	0	0	0	0	0	0	0	0	1	0	1	1	IWP
Vasticardium flavum (Linnaeus, 1758)	0	0	0	1	0	0	0	0	0	1	0	1	1	IWP
Vasticardium fultoni (G.B. Sowerby III, 1916)	**1**	1	0	0	0	0	0	0	0	0	0	0	0	WA
Vasticardium somnueki Hylleberg, 2015	0	0	0	0	0	0	0	0	1	0	0	0	0	IWP
Vasticardium luteomarginatum (Voskuil & Onverwagt, 1991)	0	0	0	0	0	0	0	0	1	0	0	0	0	IWP
Vasticardium mindanense (Reeve, 1844)	1	0	1	0	0	0	0	0	1	1	1	1	1	IWP
Vasticardium papuanum Vidal, 1996	0	0	0	0	0	0	0	0	1	1	1	1	1	IWP
Vasticardium pectiniforme (Born, 1780)	0	0	0	1	0	0	0	0	1	1	1	1	1	IWP
Vasticardium philippinense (Hedley, 1899)	1	0	1	1	0	0	0	0	1	1	1	1	1	IWP
Vasticardium serricostatum (Melvill & Standen, 1899)	0	0	0	**1**	0	0	0	0	0	0	0	0	0	E.Austr.
Vasticardium sewelli (Prashad, 1932)	1	0	1	1	0	0	0	0	1	1	1	1	1	IWP
Vasticardium subrugosum (G.B. Sowerby II, 1839)	0	0	0	0	0	0	0	0	1	1	1	1	0	IWP
Vasticardium vertebratum (Jonas, 1844)	1	1	0	1	1	0	0	1	0	1	0	1	0	IWP
Vasticardium wilsoni (Voskuil & Onverwagt, 1991)	**1**	1	0	0	0	0	0	0	0	0	0	0	0	N.Austr.
Vepricardium asiaticum (Bruguière, 1789)	0	0	0	0	0	0	0	0	1	0	0	0	0	IWP
Vepricardium coronatum (Schröter, 1786)	0	0	0	0	0	0	0	0	1	1	0	1	0	IWP
Vepricardium incarnatum (Reeve, 1844)	0	0	0	0	0	0	0	0	0	0	1	1	0	IWP
Vepricardium multispinosum (G.B. Sowerby II, 1839)	1	1	0	1	0	0	0	0	1	1	0	1	1	IWP
Vepricardium rubrohamatum Voskuil & Onverwagt, 1988	0	0	0	0	0	0	0	0	0	0	1	1	0	IWP
Vepricardium sinense (G.B. Sowerby II, 1839)	0	0	0	0	0	0	0	0	1	0	0	0	0	IWP
Total	**66**	**50**	**37**	**61**	**5**	**3**	**4**	**6**	**61**	**80**	**84**	**91**	**78**	

	DMP (total)	DMP (excl. OSS)	NOR	SOL	FLN	TAS	PER	SA	WI	CEI	PHI	WCT	ECT
Endemics	**9**			**2**				**2**					
Regional endemicity	**0.14**			**0.03**				**0.33**					

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A new species of *Boeckella* (Copepoda: Calanoida) from arid Western Australia, an updated key, and aspects of claypan ecology

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ABSTRACT – *Boeckella pilkililli* sp. nov. is described from a single, turbid, freshwater claypan located in the arid zone of Western Australia. The type locality is currently the only known location for the species. It was collected during an opportunistic survey of wetlands in the State's arid zone following a significant summer rainfall event in 2014. The most important diagnostic feature is located on the distal segment (B2) of the 2-segmented basipodite of the male fifth right leg where the distal inner edge is grossly transformed into a large, blunt, tongue-like outgrowth. As with other *Boeckella* inhabiting temporary wetlands, *B. pilkililli* sp. nov. is a relatively large species. A mini-review of claypan ecology and a discussion of ecological aspects of body size and shape in *Boeckella* are included. An updated key to species of *Boeckella* occurring in the Australasian region is also presented. This incorporates three additional species.

KEYWORDS: *Boeckella pilkililli*, claypans, arid zone, wetlands, aquatic invertebrates, Australia, Zealandia

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INTRODUCTION

Twenty species *of Boeckella* from Australasia (Australia and Zealandia) were recognised in Bayly's (1992) comprehensive work on the non-marine Centropagidae. The only additions to this have been *Boeckella spinogibba* Defaye, a species endemic to New Caledonia (Defaye, 1998), and *Boeckella timmsi* Bayly recorded from a shallow turbid claypan in Queensland (Bayly 1998). The recent discovery of the new species described below from a single shallow, turbid, freshwater claypan in Western Australia (WA) brings the total number of species now known from this region to 23, with 53 now known worldwide.

In Australia, many wetlands (including claypans) are ephemeral in nature, and those in more arid areas may fill only after significant, episodic rainfall events and then hold water for only a few weeks to a few months (Hancock and Timms 2002). Such unpredictable filling, combined with difficult access to many of these wetlands after rain, constrains surveying for aquatic invertebrate fauna in the arid zone. Consequently, the aquatic fauna has been documented from only a small number of arid zone claypans during biological surveys of the southern Carnarvon Basin, Wheatbelt, Pilbara, and Goldfields regions of WA (Halse et al. 2000; Pinder et al. 2004; Pinder et al. 2010; Quinlan et al. 2016) and of the Paroo region in New South Wales and south-western Queensland (e.g. Hancock and Timms 2002; Timms and Boulton 2001) in eastern Australia. Many of these arid zone claypans are turbid, caused by the suspension of fine sediments, and typically have a 'muddy' appearance. While species richness is often lower in these turbid pans than other wetland types, they can comprise a unique fauna (e.g. Hancock and Timms 2002; Timms and Boulton 2001).

Specimens of the new *Boeckella* were collected in March 2014 during an opportunistic survey of a number of ephemeral wetlands (including two turbid claypans that had not been sampled previously) in WA's arid zone, following significant summer rainfall (Quinlan et al. 2016). The collection locality is within the Matuwa and Kurrara Kurrara Indigenous Protected Area (IPA), an area jointly managed by Martu (Tarlka Matuwa Piarku Aboriginal Corporation) traditional owners and the State Government of Western Australia (via Department of Biodiversity, Conservation and Attractions; Figure 1).

A description of this new species follows and includes an update to Bayly's (1992) original key for *Boeckella* species occurring in the Australasian region. This key incorporates all three of the post-1992 species, *B. spinogibba, B. timmsi and B.* sp. nov.

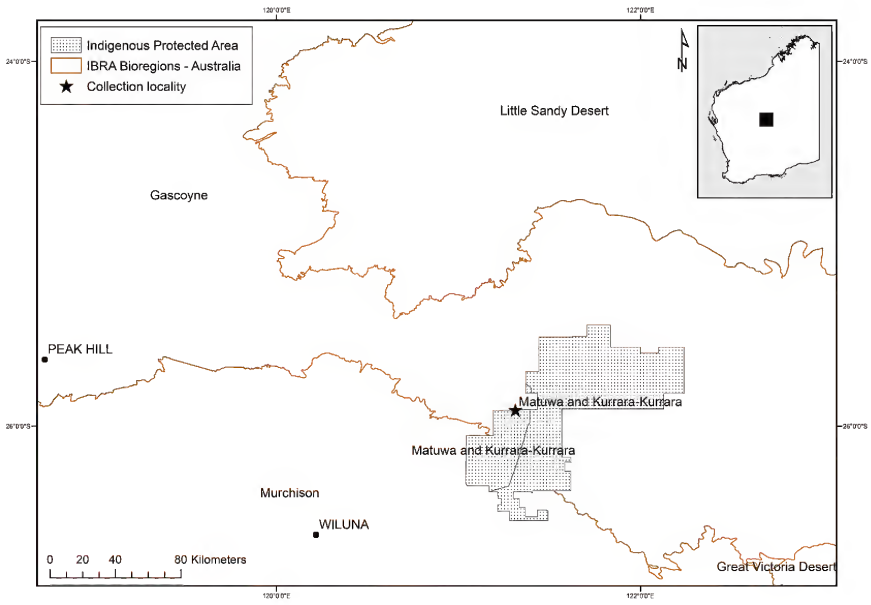

FIGURE 1 Map showing the collection locality for *Boeckella pilkililli* sp. nov. within the Matuwa and Kurrara Kurrara Indigenous Protected Area in Western Australia. Bioregions (IBRA7 http://www.environment.gov.au/land/nrs/science/ibra#ibra) are also illustrated.

MATERIAL AND METHODS

FIELD METHODS

Copepods were collected by two methods: a 50 m sweep of a plankton net (50 µm mesh) through open water only, and a 50 m sweep of a coarser net (250 µm) through benthic sediments and open water. Samples were immediately preserved with 100% ethanol. Turbidity (NTU), electrical conductivity (µS cm^{-1}), salinity (g L^{-1}), water temperature (°C) and pH were measured in-situ using hand held calibrated meters (TPS WP-81 and WP-88).

LABORATORY PROCEDURES

Calanoids were hand-picked from preserved samples, dissected and mounted on slides with polyvinyl lactophenol mountant. Whole specimens were measured using a Leica MZ16 stereomicroscope. Line drawings of several appendages (Figures 3A–B, 4C–D) were made by Jane McRae using a camera lucida attached to a Leica DM2500 differential interference compound microscope. A whole female specimen was drawn (J. McRae, figure 4B) using a camera lucida attached to a Leica MZ16 dissecting microscope. All scanning electron microscopy (SEM) work and images were undertaken by Dr. Russell Shiel. The specimens were prepared by dehydration through graded ethanol concentrations (50%, 75% and 100%), critical-point dried, transferred to an aluminium stub, and coated with carbon using a Quorum Q150TE carbon coater. Specimens were then examined with a Quanta 450FEG microscope. Material was deposited in the Western Australian Museum (WAM), Perth.

SYSTEMATICS

Subclass Copepoda H. Milne-Edwards, 1840

Order Calanoida Sars, 1903

Family Centropagidae Giesbrecht, 1893

Genus *Boeckella* De Guerne and Richard, 1889

***Boeckella pilkililli* sp. nov.**

Figures 2A–C, 3A–D and 4A–D

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MATERIAL EXAMINED

Holotype

Australia: *Western Australia*: male, collected from a shallow, temporary, turbid, freshwater claypan situated within the Matuwa and Kurrara Kurrara Indigenous Protected Area (Figure 1), 150 km north-east of Wiluna (25°54'40.6"S, 121°18'46.6"E). Collected by K Quinlan and J Futter, 17 March 2014 (WAM C70150, dissected on slide).

Allotype

Australia: *Western Australia*: female, collected by K Quinlan and J Futter, 17 March 2014 from the type locality (WAM C70151, dissected on slide).

Paratypes

Australia: ***Western Australia*****:** All specimens collected by K Quinlan and J Futter (17 March 2014) from the type locality. 1 male, (WAM C70152, dissected on slide); 1 female, unmounted whole animal in vial with 100% ethanol (WAM C70153); 3 males and 3 females, unmounted whole animals in vial with 100% ethanol (WAM C70154); 2 males mounted on aluminium stub for SEM images (WAM C70155).

DIAGNOSIS

This species is easily distinguishable from all other *Boeckella* by the large, blunt, tongue-like outgrowth observed on the inner edge of the B2 segment of the male fifth right leg. Of the species described to date, the new species shares some morphological affinity with *Boeckella geniculata* Bayly, which has a somewhat similar outgrowth on the right B2 segment, albeit with a markedly different shape. However, the new species differs from *B. geniculata* in many respects, including the lack of a pseudochelate right Re claw, in addition to differences in the structure and form of both the left and right Ri segments.

DESCRIPTION

In the following description we follow the terminology, conventions and abbreviations set out in Bayly (1992, figure 1) for legs 1–5. Alternative terms for our use of B1 and B2 are coxa and basis respectively and for Re and Ri, alternative terms are exopodite and endopodite respectively. Additionally we use the symbol 'X' to mean 'times' in the multiplication sense.

Male

Size: Length of prosome (measured along midline) ranges from 1.48–1.83 mm (mean 1.66 mm; n = 9); length from front of prosome to end of caudal rami 2.30–2.67 mm (mean 2.47 mm; n = 9).

Antennule, antennae and buccal appendages shown in Figures 2A and 2B.

Antennule: Left antennule 25-segmented, as in female. Right antennule 22-segmented, hinged between segments 18 and 19.

Antennae: Re 7-segmented, terminating in 3 setae. Ri 2-segmented. Ri2 prolonged by a lobe, giving the appearance of a third segment, but with no complete suture line visible. Proximal segment with 8 setae and lobe with 6 long setae, 1 shorter, thinner seta, and a row of spinules on inner margin.

Labrum: rounded anterior edge, ornamented with a dense fringe of long hairs (Figure 2A).

Mandible: Masticatory edge with 8 teeth and 1 spinulose seta. Re of palp 4-segmented, Ri of palp 2-segmented, proximal segment with 4 setae, terminal segment with 8 setae and a row of spinules on the inner margin.

Maxillule: External lobe bearing usual 9 plumose setae, internal lobe with 9 + 4 spine-like setae; B1 endites with 4 setae. B2 with 5 marginal setae, Ri 2-segmented, separated from B2, with 4 setae on proximal segment and 5 on distal segment. Re unsegmented with 9 setae.

Maxilla: The first endite (proximal) bearing 3 long spinulated setae and 2 shorter setae. Endites 2–4 bearing 2 long spinulated and 1 shorter setae. The fifth endite bears 2 long spinulated setae, 1 shorter seta and 1 large spine-like seta. Ri 3-segmented with setation pattern: 2, 1, 2.

Maxilliped: B1 segment slightly shorter than B2, bearing a submarginal row of fine spinules along the distal margin of segment. B2 with a submarginal row of fine spinules along the proximal inner half and 3 setae along the distal inner half of this segment. Ri 5-segmented, although full segmentation is difficult to distinguish.

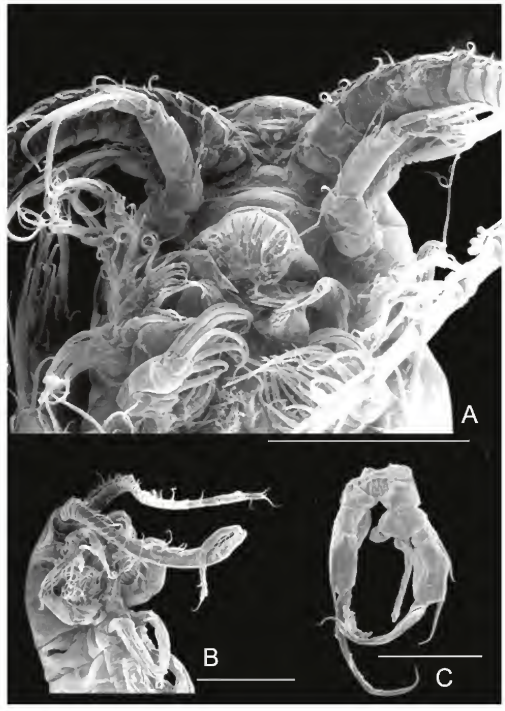


FIGURE 2 *Boeckella pilkililli* sp. nov. scanned electron micrograph (SEM) images of male paratypes, mounted on an aluminium stub (WAM C70155): A, ventral view of the anterior end of prosome; B, anterior half of body, showing hinged antennule; C, fifth leg (posterior aspect). Scale: A & C = 0.3 mm, B = 0.5 mm.

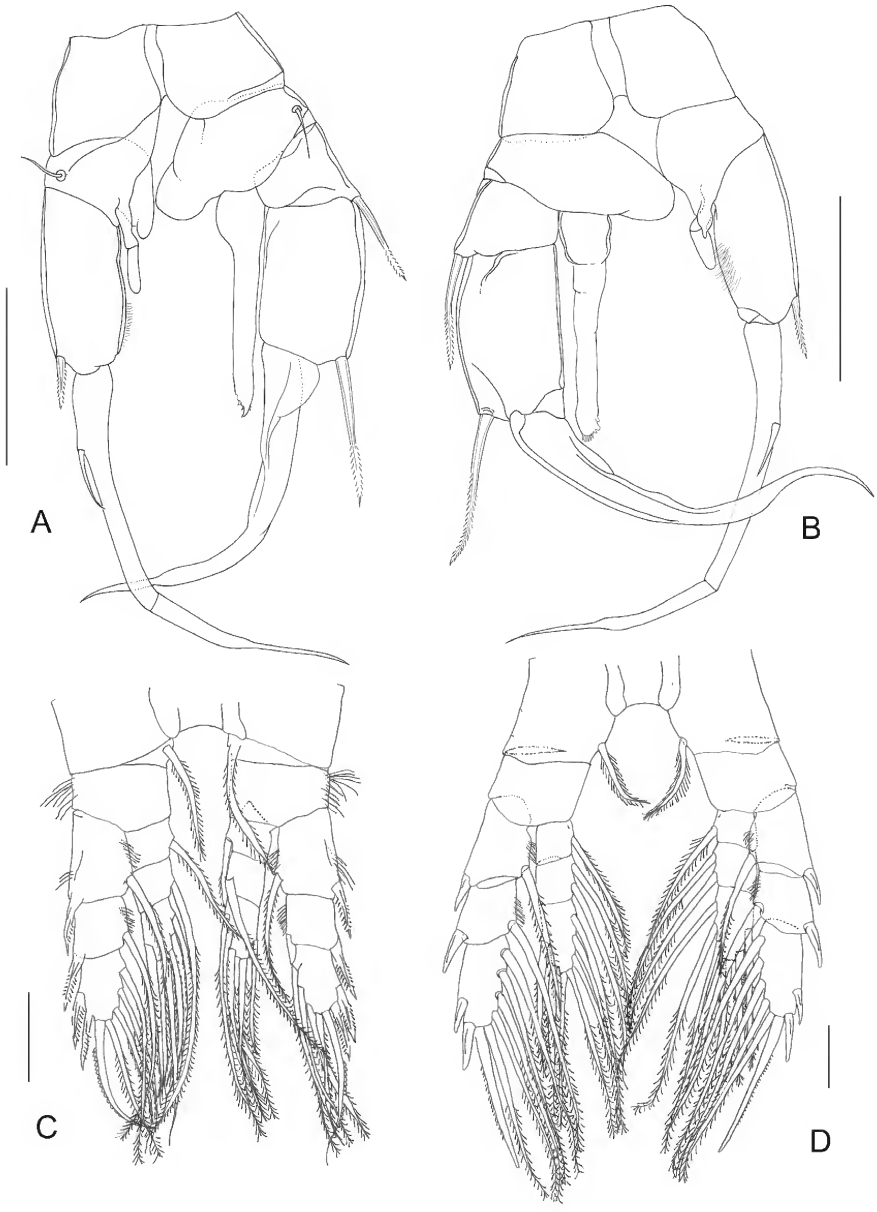


FIGURE 3 *Boeckella pilkililli* sp. nov.; A & B, posterior and anterior aspects, respectively, of male fifth legs (WAM C70150 and WAM C70152); C, first pair of legs of male holotype (WAM C70150); D, fourth pair of legs of male holotype (WAM C70150). Scale: A & B = 0.2 mm, C & D = 0.1 mm.

Urosome: Composed of 5 somites. Caudal rami symmetrical; each ending in five long terminal setae lined with fine hairs, and one shorter, thinner seta inserted on the inner distal corner. The setation pattern is same as female.

Legs 1–4: Re and Ri of legs 1–4 distinctly 3-segmented. Legs increasing in size from 1 through 4. Re1 and Re2 of each leg bearing a robust spine at outer distal corner of segment. Re3 bearing two short outer spines, one longer terminal spine on distal edge, and five long setae (four in leg 1) along inner edge of segment (Figures 3C–D). The serrations along each of the spines on segments Re1–Re3 of leg 1 are longer and more robust, than the spine serrations on legs 2–4 (Figures 3C–D). Setae all bearing fine hairs. The formulae of spines and setae for legs 1–4 are as follows:

	B1	B2	Re	Ri
leg 1	0–1	0-0	I–1; I–1; II–I–4	0–1; 0–1; 1–2–3
leg 2	0–1	0-0	I–1; I–1; II–I–5	0–1; 0–2; 2–2–4
leg 3	0–1	0-0	I–1; I–1; II–I–5	0–1; 0–2; 2–2–4
leg 4	0–1	0-0	I–1; I–1; II–I–5	0–1; 0–2; 2–2–3

Fifth leg (Figures 2C, 3A–B): Inner edge of right B2 with large, blunt, tongue-like outgrowth extending inwards beyond median plane and almost to edge of left B2 segment. *This is undoubtedly the most diagnostic character of this new species.* Right Ri swollen near basal attachment, greatly elongated, reaching well beyond junction of right Re2 and Re3 (Re claw), 6X as long as maximum width near basal attachment, with distal extremity bearing small, curved, spine-like process and several minute serrations. Right Re2 bearing long spine at outer distal corner, with length of spine equal to length of segment bearing it. Left B2 segment with small lobe at inner distal corner. Left Ri 2-segmented with terminal segment (Ri2) digitate, extending c. half-way along inner edge of left Re1. Left Re claw 2-segmented with Re2 c. 1.2X longer than Re3. Outer spine inserted at 0.3X distance along Re2. Both left and right Re claws narrow abruptly before tapering to a point at the distal extremity.

Female

Size: Length of prosome (measured mid-dorsally to exclude large 'wing' structures on last prosomite) 1.69–1.98 mm (mean 1.86 mm; n = 8); length from front of prosome to end of caudal rami 2.48–2.81 mm (mean 2.65 mm; n = 8). Prosome with pedigerous somites 1 and 2 and 4 and 5 separate. 'Wing' structures at the posterior lateral margin of last prosomite well developed and extend c. 0.8 of the way along genital compound somite (Figure 4B).

Antennule: 25-segmented. Aesthetascs on segments 1, 2, 3, 5, 7, 9, 11, 12, 14, 16, 19 and 25. Short spine present on segments 8 and 12 (Figure 4A). Antennule c. 1.8 mm in length, and when extended posteriorly reaching only as far as the posterior end of the prosome (Figure 4B). Antennae and buccal appendages as in male.

Urosome (Figure 4C): Genital compound somite c. 1.2X as long as maximum width. Free urosomites 2 and 3 approximately equal in width, but somite 3 1.3X length of somite 2. Caudal rami c. 2X as long as maximum width, each ending in five long terminal setae lined with fine hairs, and one shorter, thinner seta inserted on the inner distal corner, Caudal rami lined with hairs along innermost margins.

Legs 1–5: Re and Ri of legs 1–4 distinctly 3-segmented. Formulae of spines and setae for legs 1–4 identical to those of male. Fifth leg of female similar in size to leg one, both of which are smaller than legs 2–4. Re1 of fifth leg with one outer spine, Re2 with one outer spine and the usual centropagid inner process, Re3 with two outer spines, one terminal spine and four inner setae (Figure 4D). Ri1 of fifth leg with fine hairs on outer edge and one plumose seta on inner edge, Ri2 with one inner plumose seta, Ri3 with 2 inner, 2 terminal and 2 outer plumose setae (Figure 4D).

ETYMOLOGY

The specific name 'pilkililli' is the word for claypans in the language of the southern Martu Aboriginal people (Tarlka Matuwa Piarku Aboriginal Corporation, 2015) and refers to the habitat type from which this species was collected; noun in apposition.

It was named in consultation with Elders from the Tarlka Matuwa Piarku Aboriginal Corporation, the traditional custodians of the Matuwa and Kurrara Kurrara Indigenous Protected Area, to acknowledge the land on which it was found.

DISCUSSION

COMPARATIVE ASPECTS OF THE MALE FIFTH RIGHT BASIPODITE IN SPECIES SEPARATION

In the male fifth pair of legs of *Boeckella* the right basipodite, which has 2 segments (B1 and B2), is typically of little importance among the secondary sexual structures that allow the separation of species. There are, however, exceptions. The South American (SA) species, *B. bergi* Richard, is the only species in which the B1 is sexually transformed by having a prominent projection at the inner distal corner. Modification of the right B2, however, occurs in a minority of species:

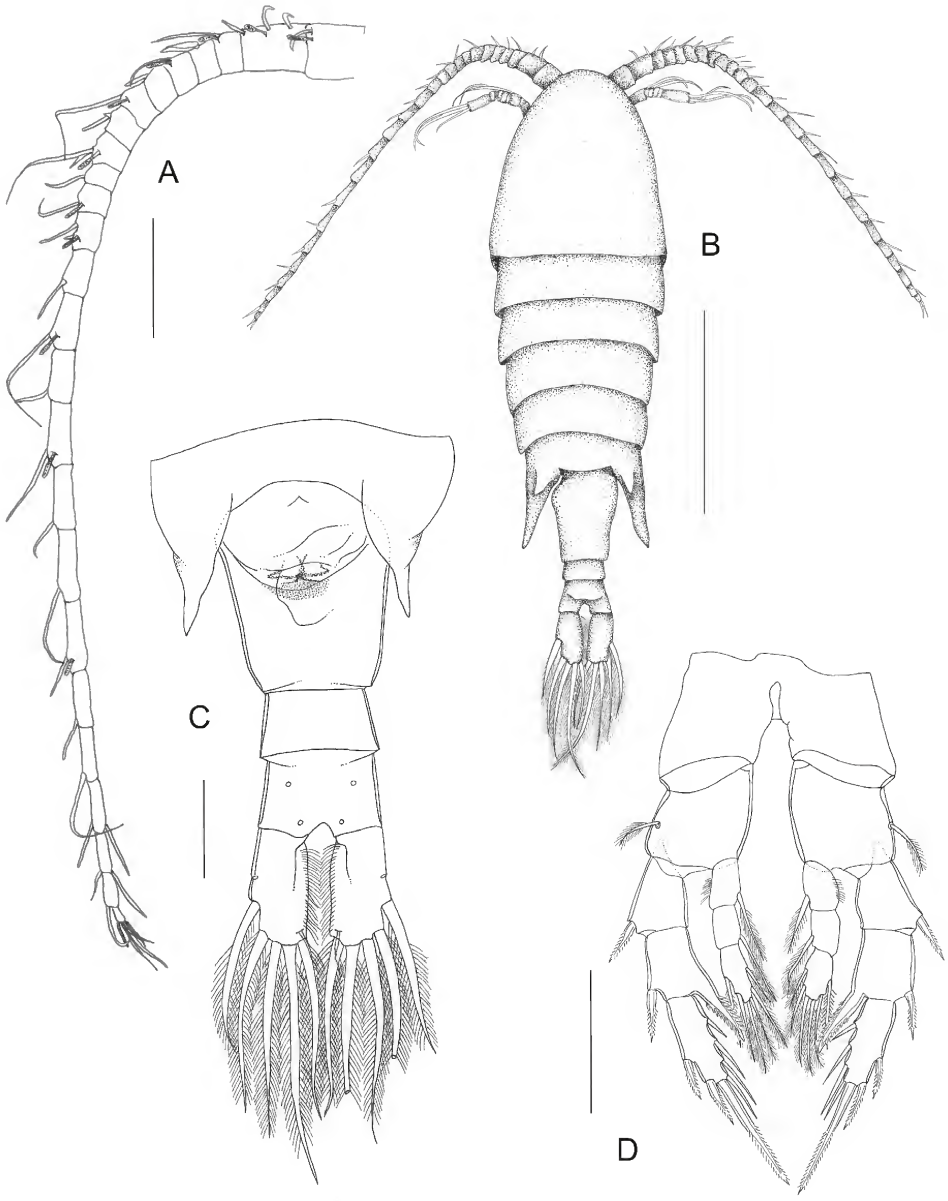


FIGURE 4 *Boeckella pilkililli* sp. nov.; A, Antennule of female allotype (WAM C70151); B, whole animal, dorsal view of female paratype (WAM C70153); C, ventral aspect of female urosome, including genital compound somite (WAM C70151). D, fifth pair of legs of female allotype (WAM C70151). Scale: A, C & D = 0.2 mm, B = 1mm.

1. in *B. rubra* Smith it bears a prominent spine at the inner distal corner;
2. in *B. geniculata* it has a broad expansion along the whole of the inner edge;
3. in *B.bispinosa* Bayly, *B.propinqua longisetosa* Smith, *B. bergi*, *B. meteoris* Kiefer (SA) and *B. poopoensis* Marsh (SA) there is a blunt projection on the inner edge.

B. pilkililli sp. nov. approximates somewhat to *B. geniculata* and joins species in group (3) in a highly exaggerated manner. The inner edge of B2 is produced into a large, tongue-like expansion that crosses the median plane. In summary, *B. pilkililli* and *B. geniculata* possess the most highly transformed male fifth right B2 in the entire genus. However, *B. pilkililli* differs markedly from *B. geniculata* in that the right Re claw is not pseudochelate, and the right Ri is straight rather than possessing a geniculate bend.

DISTRIBUTION

Boeckella pilkililli sp. nov. is currently known only from its type locality; a characteristically shallow (< 40 cm deep), temporary, turbid (turbidity 319 NTU), freshwater (salinity 0.09 g L^{-1}) claypan, which had a pH of 7.76 and a water temperature of 28.6 °C (Quinlan et al. 2016). The new species may be more widespread and associated with other turbid claypans within the Gascoyne and Murchison IBRA (Interim Biogeographic Regionalisation for Australia; Australian Government 2012) bioregions. However, additional survey opportunities to determine its distribution are limited in the short-term by the unpredictable nature of rainfall in the arid zone, the temporary nature of these pans and the difficulty in accessing them after episodic rains.

ASPECTS OF AUSTRALIAN CLAYPAN ECOLOGY

General features and life-histories of calanoids

Claypans are a distinctive aspect of the arid and semi-arid regions of Australia, and famous nineteenth century explorer, Ernest Giles, was perhaps the first (Giles 1889, vol. 1, p.39) to give a good definition of one. The use of claypans as a source of fresh water by desert Aborigines was discussed by Bayly (1999).

Williams (1985), in his general classification of temporary standing waters, assigned claypans to a distinct type ('Type D') characterised by being discrete, unpredictably filled and having fresh water. Halse et al. (2000) studied a series of claypans in the southern Carnarvon Basin, Western Australia, and found that less turbid ones, and those where water levels were still high (pre-recession phase) had higher species richness. Hancock and Timms (2002) studied the ecology of four claypans in the Paroo region of semi-arid Australia and concluded that among the more important factors characterising these habitats were: shallowness, high turbidity, short filling phase, low conductivity, highly variable temperatures and lack of vegetation. This list, which also fits the habitat of *Boeckella pilkililli* sp. nov., contains several stress factors which would suggest that claypans should contain lower species richness or a more simplified community structure than deeper, more permanent, clear-water, vegetated, freshwater ponds or lakes. In the Paroo region, where Australian claypans have been best studied, this expectation is met, but not to the extent that one would expect. Timms (2002) makes two important statements on this issue: (1) 'Compared with other wetlands in the Paroo, claypans are one of the least speciose'; (2) 'Even so they are surprisingly rich considering the lack of vegetation and the homogeneous habitat.'

There are preliminary indications that flooded claypans may contain distinctive, specialist species. Paroo crustacean species characteristic of, or known only from, claypans (Timms 2002) include: *Branchinella* 5 spp, *Ozestheria* (formerly *Caenestheria*) 2 spp, *Triops australiensis* Spencer & Hall, *Daphnia projecta* Hebert, *Moina australiensis* Sars, *Latonopsis brehmi* Petkovski, *Calamoecia* 3 spp, *Boeckella robusta* Sars and *B. timmsi*. The last mentioned species is currently known only from highly turbid claypans in the Currawinya National Park (Bayly 1998) and the Paroo region (Hancock and Timms 2002) where it appears fleetingly and very early in succession between 7 and 18 days after filling. *B. pilkililli* may approximate to a counterpart species in the western half of the Australian arid core.

The type locality filled after significant rainfall across the Gascoyne and Murchison bioregions in early and late January of 2014. Remote sensing data acquired from Landsat satellites 7 and 8, indicated that the claypan held water from 28 January to 12 May 2014. Specimens of *B. pilkililli* were collected on 17 March 2014 about 6–7 weeks after filling near the middle of the hydroperiod. We do not know when this species first appeared in the wetland, or how long it persisted, but it evidently appears later in succession than *B. timmsi*. More is known about the life-history of some other temporary-water species of *Boeckella*. *B. robusta robusta* Sars is a short-lived (c. 15–30 days after filling) species in claypans in the Paroo region (Timms 2001). *B. major* Searle matures rapidly, typically within a few weeks after a wetland fills, produces resting eggs and then disappears (Green et al. 1999). *B. pseudochelae* Searle reaches maximum numbers later, more towards the middle of a pool's hydroperiod (Morton and Bayly 1977). At this stage more information is needed to determine the life-history of *B. pilkililli*.

Ecological aspects of body size in Boeckella

Of the 22 known species of *Boeckella* in the Australasian region, *B. robusta* and *B. major* are two of the largest, with body lengths >4 mm recorded, and *Boeckella minuta* Sars, with a male body length <1.2 mm (female <1.57 mm), one of the smallest (Bayly 1964, 1978; Green et al. 1999; Timms 1968). Of the remaining species, there is considerable overlap in the range of mean body size, owing largely to the differences in size between males and females (sexual dimorphism) and differences due to seasonal variation (Bayly 1964; Bayly 1978). Despite this variation, it is noted here that *B. pilkililli* is one of the larger species of the genus, with males ranging from 2.30–2.67 mm in length (to end of caudal rami; n = 9) and females 2.48–2.81 mm in length (n = 8).

Given that body size can be quite variable, both within and between populations of a species, it has been suggested (Bayly 1978) that the actual ratio between the mean body size of males and females in a given population of a species, is a more reliable metric to use for comparison between species of *Boeckella*. According to Bayly (1978), the magnitude of sexual dimorphism is larger in some species (e.g. *B. minuta, B. symmetrica* Sars, *B. opaqua* Fairbridge and *B. bispinosa*), and less so in others (e.g. *B. rubra*, *B. nyoraensis* Searle and *B. tanea* Chapman). With such a small sample size, it is difficult to provide a statistically valid conclusion, however, for *B. pilkililli,* the ratio of female length:male length (from front of prosome to end of caudal rami) is 1.07, and is therefore not considered to be highly dimorphic. This is also true for other large species such as *B. robusta* and *B. major* (Bayly 1978).

Distinct differences in body proportions exist between calanoid copepods which occupy a limnetic habitat and those that occupy a more littoral/pond habitat, as discussed in Timms (1979). To better understand the type of habitat perhaps utilised by *B. pilkililli* sp. nov, body proportions for this new species were quantified. Timms (1979) calculated ratios of metasomal length:metasomal width (ML:MW) and antennule length:metasomal length (AL:ML) to determine the variation in body build between species. His calculations of so called 'metasomal' (=prosomal) length and width are equivalent to prosomal length (PL) and prosomal width (PW). The ratio of PL:PW for males of *B. pilkililli* was 2.57 ± 0.19 SD (n = 9) and 2.62 ± 0.18 (n = 8) for females The AL:PL ratio was 1.04 ± 0.08 for males and 0.98 ± 0.08 for females. With only a limited sample size, a more statistically valid conclusion is difficult. However, these body proportions for *B. pilkililli* are intermediate between the ratios for littoral and limnetic copepods (2.1–2.3 and 3.0–3.4 respectively) given in Timms (1979). *B. pilkililli* is therefore considered to be of a medium build with short antennules, having a AL:PL ratio less than that of littoral species such as *B. major* (e.g. <1.28). These body proportions would suggest that *B. pilkililli* is unlikely to be limnetic in habit. If this hypothesis is correct, it may be important in sampling claypans to ensure collection from all habitats (benthic and limnetic) as was done in the present study. Traditionally, planktonologists try to avoid doing this because 'dirty' collections are difficult to examine.

Calamoecia halsei Bayly, another centropagid calanoid, co-existed with *B. pilkililli* at the type locality. It is also an ephemeral wetland specialist and was easily distinguished from the new species by the clear difference in size. *Boeckella pilkililli* is approximately two times larger, with a mean body length (to end of caudal rami) of 2.47 mm for males and 2.65 mm for females, whereas the mean body length of *Calamoecia halsei* was 1.10 mm for males (n = 5) and 1.30 mm for females (n = 5). The co-occurrence of calanoids is common in the genera *Boeckella* and *Calamoecia* in WA (e.g. Bayly 1982, 1985; Maly and Maly 1997; Maly et al. 1997; Quinlan et al. 2016; Storey et al. 1993; Williams 1979) and so too is size difference between species of co-occurring calanoids (e.g. Maly and Maly 1997; Halse and McRae 2001).

An updated key to the described Australasian species of *Boeckella,* based on characters of the male fifth leg, is provided below. As far as practicable, the key has remained true to Bayly's (1992) original dichotomous key. The first of three new additions (*B. pilkililli*) enters the key at couplet 7. From there, the original key is altered, with *B. timmsi* appearing in the revised couplet 10 and *B. spinogibba* appearing in the revised couplet 18. *B. spinogibba* and the three species endemic to New Zealand (*B. dilatata* Sars, *B. hamata* Brehm and *B. tanea*) are denizens of the largely sunken continent of Zealandia with which they may be presumed to have had an ancient association (Bayly and Boxshall 2009; Mortimer *et al.* 2017).

AN UPDATED KEY TO SPECIES OF *BOECKELLA* OCCURRING IN THE AUSTRALASIAN REGION (AUSTRALIA AND ZEALANDIA)

(Key features refer to the male fifth leg unless otherwise stated. All figures in the key, with the exception of Figures 11, 13 and 21, are taken (with permission) from Bayly, 1992; pp. 11–19).

1. Re3 of *female* fifth legs with 2 spines (Figure 5A) (For male fifth legs see Figure 5B). ..... *B. minuta* Sars, 1896

   Re3 of *female* fifth legs with more than 2 spines 2

2. Right Re claw pseudochelate at extremity (see arrows in Figures 6–8) 3

   Right Re claw not pseudochelate (tapering smoothly to single point) at extremity 5

3. Right Ri extending no more than halfway along inner edge of right Re2 (Figure 6). ..... *B. shieli* Bayly, 1985

   Right Ri extending to distal limit of right Re2 or beyond..... 4

4. Right B2 extending inwards at least as far as median plane; right Ri 3-segmented, without basal inner projection, distal quarter bent outwards through about 45 degrees (Figure 7). ..... *B. geniculata* Bayly, 1964

   Right B2 not extending inwards as far as median plane; right Ri extremely long but 1-segmented, with basal inner projection, distal quarter not bent outwards (Figure 8). ..... *B. pseudochelae* Searle, 1912

5. Right B2 with prominent spine at inner distal corner, half as long as, and in addition to, right Ri (see arrow Figure 9). ..... *B. rubra* Smith, 1909

   Right B2 with no spine (but sometimes with blunt outgrowth) at inner distal corner in addition to right Ri..... 6

6. Right Ri with 2 or 3 spines at distal extremity (see arrow Figure 10). ..... *B. bispinosa* Bayly, 1967

   Right Ri either smoothly rounded, or with single spine-like process at distal extremity..... 7

7. Right B2 with large, blunt, tongue-like outgrowth at inner distal corner, extending inward beyond median plane; right Ri elongate, extending beyond junction of right Re2 and Re3 (Figure 11). ..... *B. pilkililli* sp. nov. (A large species endemic to Western Australia. Recorded from a shallow, turbid, freshwater claypan in the State's inland).

   Right B2 lacking large, blunt, tongue-like outgrowth at inner distal corner..... 8

8. Distance between right B2 and left B2 at level of their attachment to B1 greater than proximal width of either right or left B2 (see arrows Figure 12)..... *B. dilatata* Sars, 1904

   Distance between right B2 and left B2 at level of their attachment to B1 less than proximal width of either right or left B2..... 9

9. Right Ri with inner projection or sharp angle near proximal attachment to right B2 (see arrows Figure 13–17)..... 10

   Right Ri lacking inner projection or sharp angle near proximal attachment to right B2..... 14

10. Right Ri sub-triangular and 2- or 3-segmented, reaching less than half-way along inner edge of right Re2 (Figure 13). ..... *B. timmsi* Bayly, 1998 (A rare species, collected from a shallow, highly turbid freshwater claypan in Queensland) (Note: Figure 13 is after Bayly, 1998).

    Right Ri not sub-triangular, typically 1-segmented and of variable length (Figures 14–17)..... 11

11. Left B2 with conspicuous teeth attached in vicinity of inner distal corner (see arrow or arrows in Figures 14–15). 12

    Left B2 with no conspicuous teeth attached in vicinity of inner distal corner..... 13

12. Left B2 with teeth in single row (see single arrow Figure 14)..... *B. triarticulata* Thomson, 1883

    Left B2 with teeth in two rows (or apparently so) (see two arrows Figure 15)..... *B. fluvialis* Henry, 1922

13. Right Ri extending only c. half-way along right Re2, right Re claw with abrupt narrowing near distal extremity (see arrow Figure 16)..... ..... *B. hamata* Brehm, 1928

    Right Ri extending to distal extremity of right Re2, right Re claw tapering evenly to distal extremity (Figure 17). ..... *B. robusta* Sars, 1896

14. Left Rel long relative to right Re, distal extremity lying directly opposite distal extremity of right Re2 (see dotted lines at right angles in Figures 18–20). 15

    Left Rel short relative to right Re, distal extremity lying directly opposite a point only 0.4–0.7 times distance along inner edge of right Re2 (in nearly all cases it is the point of insertion of the outer spine of left Re2, instead of the extremity of left Rel, that lies opposite the extremity of right Re2)..... 17

15. Right Ri with 45° bend (Ri3 at angle of 45° to long axis of Ri1) (see arrow Figure 18); right Re claw not recurved, narrowing abruptly about ⅔ length from distal extremity (see arrow Figure 18). ..... *B. nyoraensis* Searle, 1912

    Right Ri straight (typically distinctly or indistinctly 2- or 3-segmented); right Re claw recurved and tapering evenly to distal extremity.....16

16. Left B2 produced at inner distal corner into pointed process bearing small spines along inner edge only, this segment with no upraised semi-circular lobe on anterior aspect (Figure 19). ..... *B. delicata* Percival, 1937

    Left B2 produced at inner distal corner into pointed process bearing small spines on both inner and outer edges, this segment with upraised semi-circular lobe on anterior aspect immediately proximal to pointed process (Figure 20). ....*B. montana* Bayly, 1964

17. Right Ri 1-segmented and narrowing slightly towards distal extremity (Figures 21–23).....18

    Right Ri 2- or 3-segmented (sometimes indistinct), with variable articulation. 20

18. Left Ri small, reduced to a triangular plate and hidden by a rounded process covered in thick spiniform hairs; left B1 noticeably longer than right B1 (Figure 21) .....*B.spinogibba* Defaye, 1998 (A small species collected from shallow water bodies in New Caledonia) (Note: Figure 21 is after Defaye, 1998).

    Left Ri large, 2-segmented, extending at least ⅔ distance along inner edge of left Re1. 19

19. Outer spine left Re2 (= basal portion left Re claw) large, extending to distal extremity of left Re2 (see arrow Figure 22) or at least ⅔ distance from point of insertion to distal extremity of Re2 ..... *B. opaqua* Fairbridge, 1945

    Outer spine left Re2 (= basal portion left Re claw) small, extending only about half distance from point of insertion to distal extremity of Re2 (see arrow Figure 23). ..... *B. symmetrica* Sars, 1908

20. Left Ri thumb-like (typically 2-segmented), at least twice as long as basal width, extending about 0.3 times distance along inner edge of left Re1 (see arrow Figure 24) (large body size; length both sexes > 2.5mm). .....*B.major* Searle, 1938

    Left Ri vestigial (1 sub-circular segment largely obscured between inner distal corner of left B2 and inner proximal corner of left Re1), not extending along inner edge of left Re1 (see small dotted circles in Figures 25, 27–28) (small or medium body size; length both sexes < 2.5 mm).....21

21. Right Re claw recurved (initially turned inwards, then turned outwards towards extremity) (see arrows Figure 25). .....*B. saycei* Sars, 1908

    Right Re claw not recurved (continuously curved inwards from proximal attachment to extremity).. 22

22. Left B2 with large, complex (bearing c. 6 small teeth and a small terminal cone-like process) projection at inner distal corner, extending c. 0.5 times distance along inner edge of left Re1 (Figure 26). ..... *B. tanea* Chapman, 1973

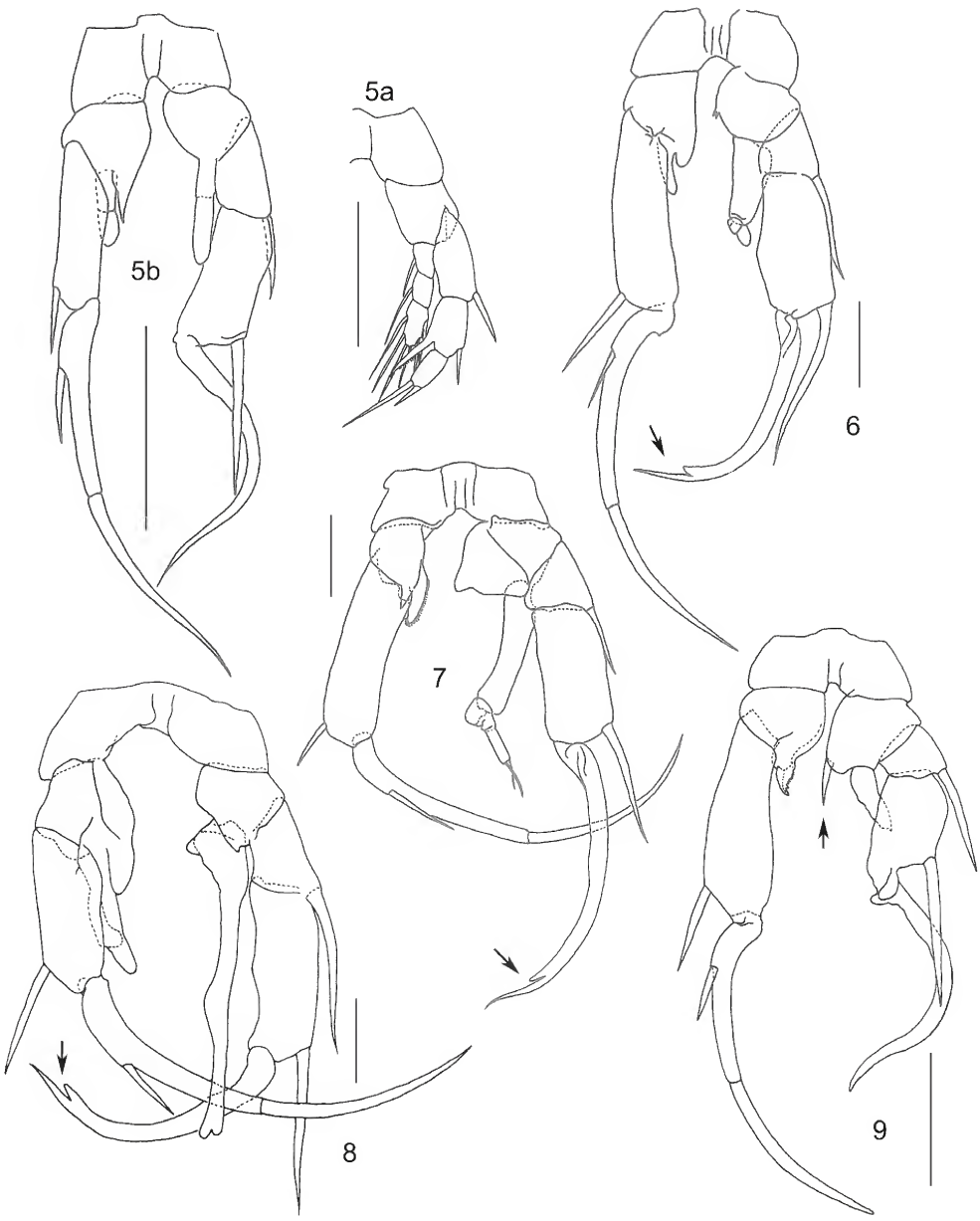
    Left B2 with small, simple projection at inner distal corner, extending no more than 0.25 times distance along inner edge of left Re1. 23

23. Mean ratio (length right Ri1)/(length right Ri2 plus length right Ri3) less than 2.5 (Figure 27). .....*B. propinqua propinqua* Sars, 1904

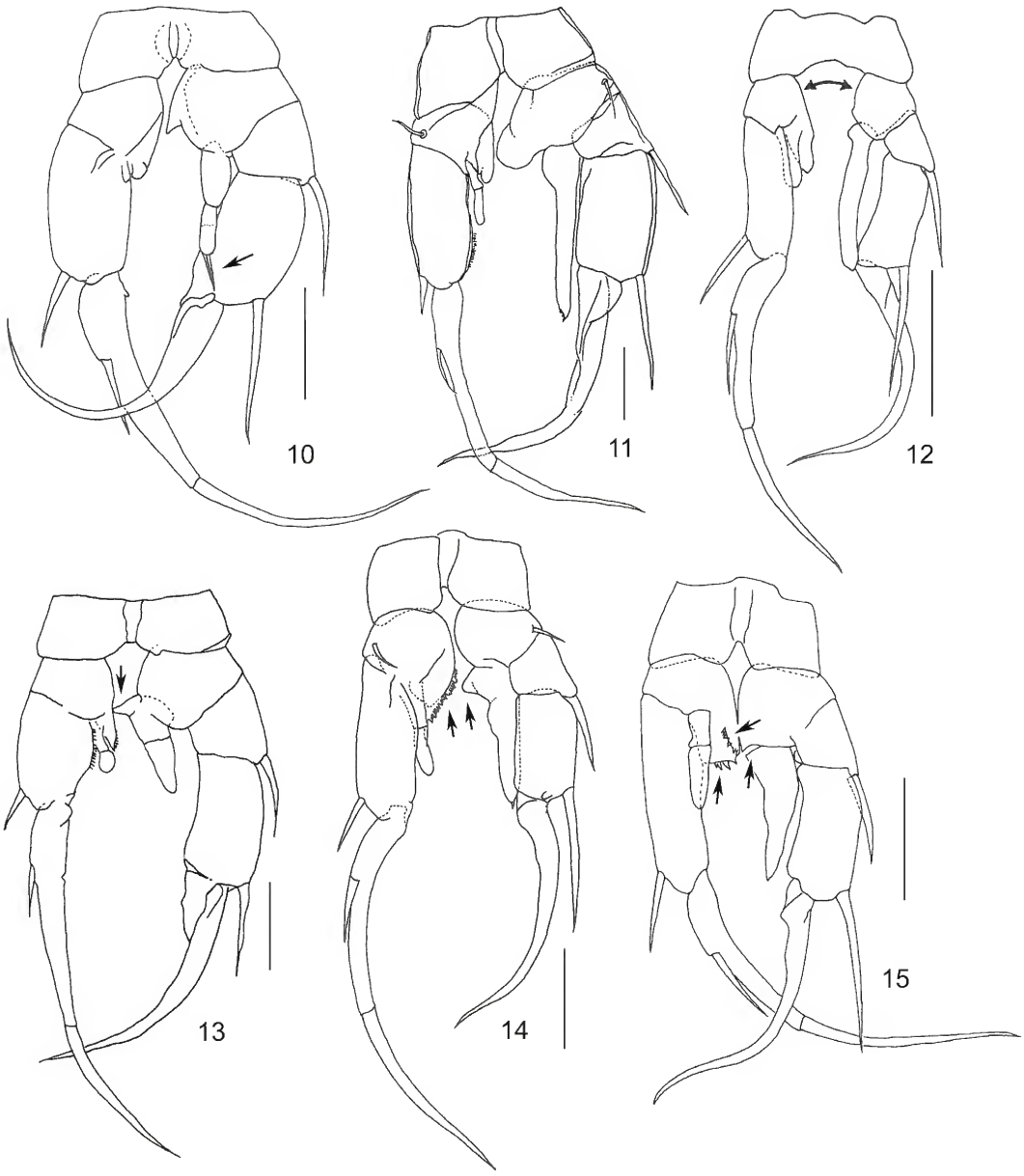
    Mean ratio (length right Ri1)/ (length right Ri2 plus length right Ri3) greater than 2.5 (Figure 28). ..... B. *propinqua longisetosa* Smith, 1909

ACKNOWLEDGEMENTS

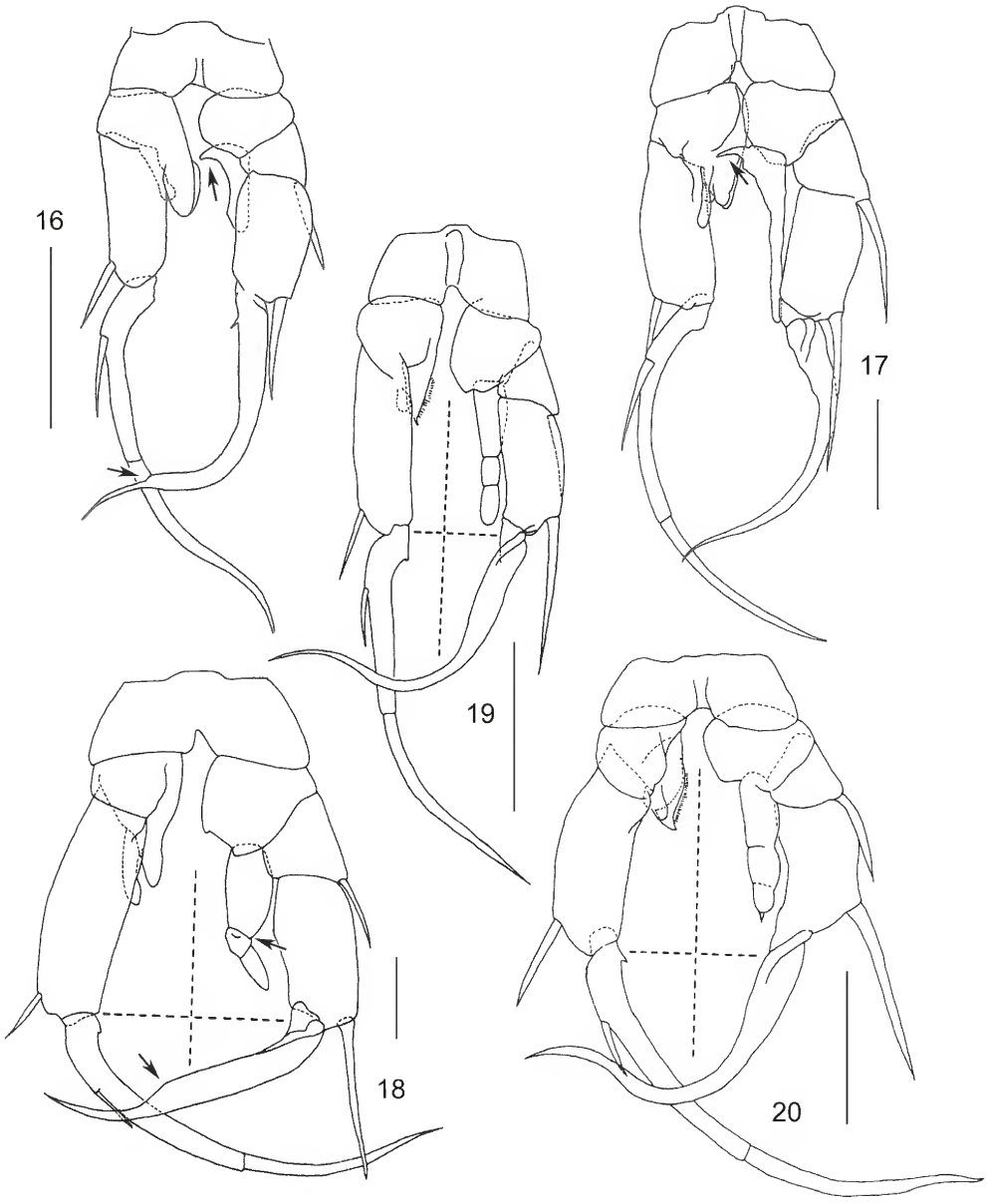
We thank the Martu (Tarlka Matuwa Piarku Aboriginal Corporation) for accepting the honour of naming this new species, and to Hamish Morgan and Stephen van Leeuwen for valued assistance in this process. We are grateful to Jane McRae for specimen illustrations (3A–B, 4B–D) and are indebted to Russell Shiel and the staff of Adelaide Microscopy (Angus Netting and Lyn Waterhouse) for providing, and assisting with, the SEM work and images. Acknowledgement and thanks go to Ian Keally, Jennifer Jackson and Julie Futter for advice on site selection and field assistance during the survey work and to Rebecca Coppen for technical support in the laboratory. We also thank Adrian Pinder, Juliet Wege, Bart Huntley and David Cale for providing assistance with components of the manuscript. Finally we thank the two reviewers for their valued comments on the manuscript. Funding of this work was provided by the WA Department of Biodiversity, Conservation and Attractions (Science and Conservation, and Goldfields Region).



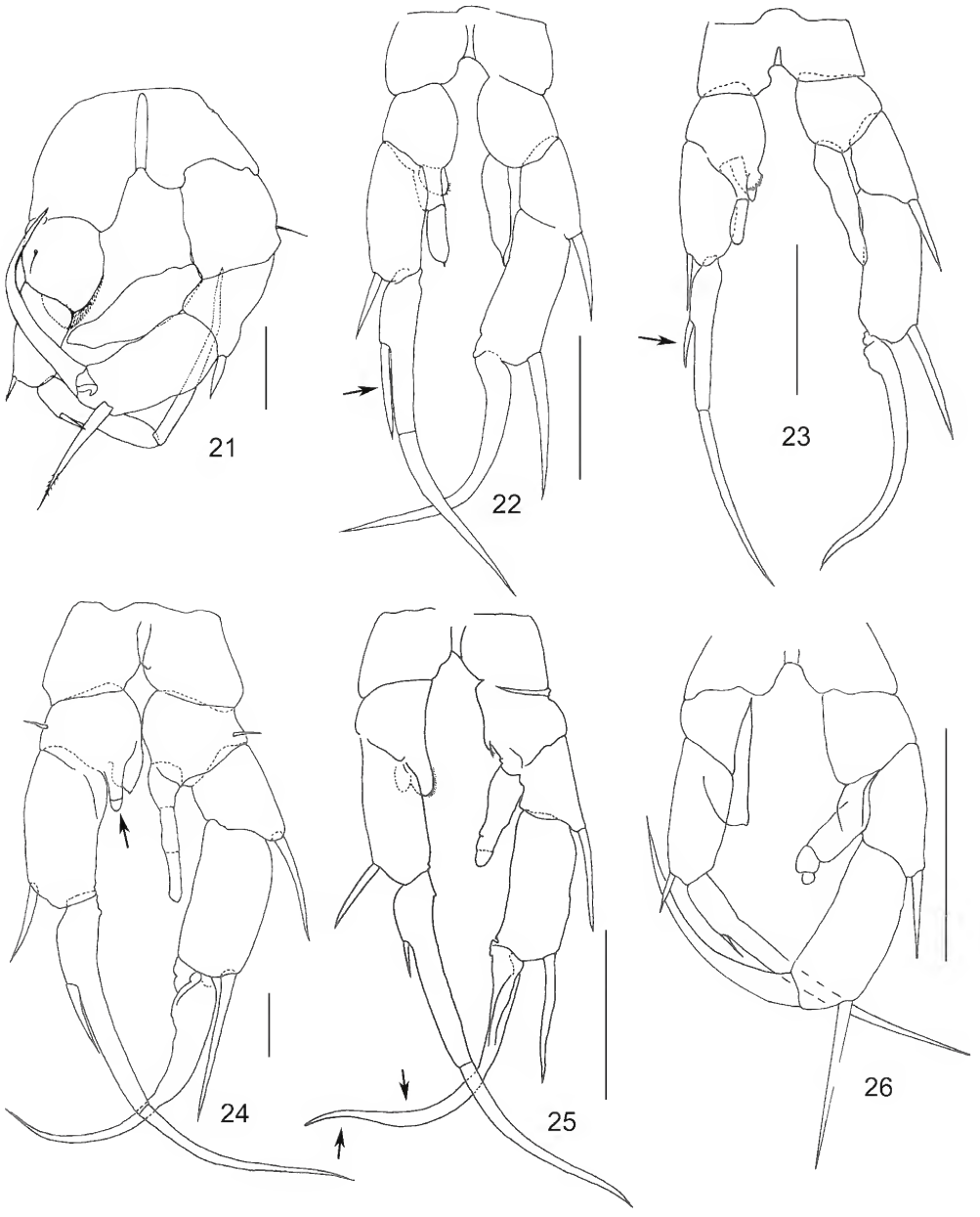
FIGURES 5–9 *Boeckella* fifth legs (posterior aspect); 5A, *B. minuta* female right fifth leg; 5B, *B. minuta* male fifth legs; 6, *B. shieli* male fifth legs; 7, *B. geniculata* male fifth legs; 8, *B. pseudochelae* male fifth legs; 9, *B. rubra* male fifth legs. Scale = 0.1 mm.



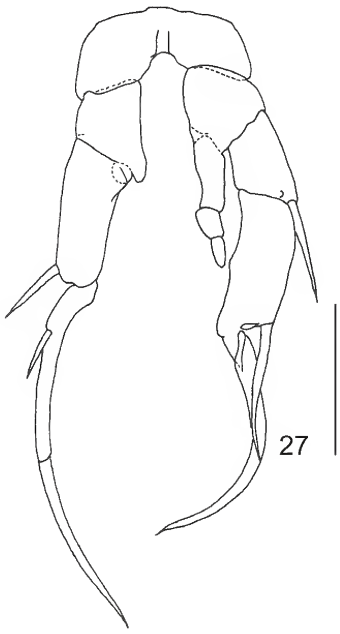
FIGURES 10–15 *Boeckella* male fifth legs (posterior aspect); 10, *B. bispinosa*; 11, *B. pilkililli* sp. nov; 12, *B. dilatata*; 13, *B. timmsi*; 14, *B. triarticulata*; 15, *B. fluvialis*. Scale = 0.1 mm.

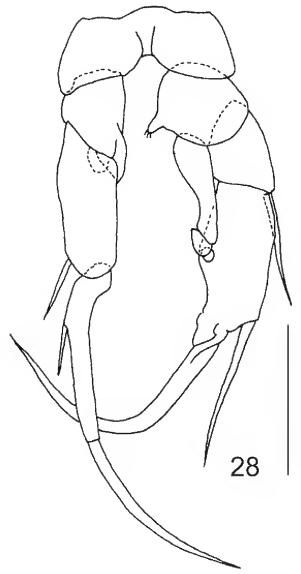


FIGURES 16–20 *Boeckella* male fifth legs (posterior aspect); 16, *B. hamata*; 17, *B. robusta*; 18, *B. nyoraensis*; 19, *B. delicata*; 20, *B. montana*. Scale = 0.1 mm.



FIGURES 21–26 *Boeckella* male fifth legs (posterior aspect); 21, *B. spinogibba*; 22, *B. opaqua*; 23, *B. symmetrica*; 24, *B. major*; 25, *B. saycei*; 26, *B. tanea*. Scale: 21 = 0.05 mm, 22-26 = 0.1 mm





FIGURES 27–28 *Boeckella* male fifth legs (posterior aspect); 27, *B. propinqua propinqua*; 28, *B. propinqua longisetosa*. Scale = 0.1 mm.

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APPENDIX Updated alphabetical checklist of Australian and Zealandia species (and subspecies) in the genus *Boeckella*.

B. bispinosa Bayly, 1967
B. delicata Percival, 1937
B. dilatata Sars, 1904
B. fluvialis Henry, 1922
B. geniculata Bayly, 1964
B. hamata Brehm, 1928
B. major Searle, 1938
B. minuta Sars, 1896
B. montana Bayly, 1964
B. nyoraensis Searle, 1912
B. opaqua Fairbridge, 1945
B. pilkililli sp. nov.
B. propinqua longisetosa Smith, 1909
B. propinqua propinqua Sars, 1904
B. pseudochelae Searle, 1912
B. robusta robusta Sars, 1896
B. robusta maxima Bayly, 1964
B. rubra Smith, 1909
B. saycei Sars, 1908
B. shieli Bayly, 1985
B. spinogibba Defaye, 1998
B. symmetrica Sars, 1908
B. tanea Chapman, 1973
B. timmsi Bayly, 1998
B. triarticulata (Thomson, 1883)

RECORDS OF THE WESTERN AUSTRALIAN MUSEUM 32 207–216 (2017) DOI: 10.18195/issn.0312-3162.32(2).2017.207-216

A new subspecies of *Candalides geminus* Edwards & Kerr, 1978 (Lepidoptera: Lycaenidae) from the Northern Territory, Australia

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ABSTRACT – *Candalides geminus gagadju* ssp. nov. from the 'Top End' of the Northern Territory is described, illustrated and compared with the nominate subspecies *C. geminus geminus* Edwards & Kerr, 1978 and *C. erinus* (Fabricius, 1775). It differs from *C. geminus geminus* by four fixed phenotypic character states, but not in genitalic morphology nor in morphology of the immature stages. The taxon is restricted to sandstone blocks in the higher rainfall areas where it is sympatric with *C. erinus*, narrowly sympatric with *C. delospila* (Waterhouse, 1903), but allopatric with *C. geminus geminus* from eastern Australia. *Candalides geminus gagadju* breeds in heathy woodland where the larval food plants (*Cassytha filiformis* and *C. capillaris*) grow as hemi-parasitic vines. Although material of the subspecies has been known in museum collections for at least 45 years (earliest collections date to October 1972), its taxonomic identity, comparative morphology, distribution and biology have remained poorly known. During 2007–2014, I conducted detailed field investigations in north-western and northern Australia to address these substantial knowledge gaps.

KEYWORDS: Candalidini, Kakadu National Park, *Nesolycaena*, taxonomy, Top End

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INTRODUCTION

The lycaenid tribe Candalidini, as circumscribed by Eliot (1973), is endemic to the Australian zoogeographic region where it is restricted to Australia and mainland New Guinea and its adjacent islands (Parsons 1998; Braby 2000). It currently contains 37 species and 23 subspecies (60 taxa) referred to two genera (*Candalides* Hübner, 1819 and *Nesolycaena* Waterhouse & Turner, 1905), and thus represents a significant evolutionary radiation and characteristic component of the Australo-Papuan butterfly fauna. Since the revisionary work of Tite (1963), a remarkable number of new taxa have been described during the past 30 years (Parsons 1986; d'Apice and Miller 1992; Braby 1996, 2008; Williams and Bollam 2001; Tennent 2004; Braby and Douglas 2004; Müller 2013, 2014; Müller and Tennent 2016), suggesting that the taxonomic inventory of the tribe is incomplete and that additional taxa may await discovery.

As part of a broader study investigating the phylogenetic relationships and generic classification of the Candalidini, the purpose of this paper is to determine the species boundary of an isolated population of *Candalides* from the 'Top End' of the Northern Territory. The population was first recorded by Kikkawa and Monteith (1980) based on a small series of specimens collected from Radon Creek on the Arnhem Land plateau, and it had been assigned to the monotypic species *C. geminus* Edwards & Kerr, 1978. Elsewhere, *Candalides geminus* is known only from eastern Australia, mainly on or west of the Great Dividing Range from Cape York Peninsula, Queensland to Barryrennie [Conimbla National Park] near Cowra, New South Wales (Edwards and Kerr 1978), where it has a patchy distribution with populations restricted to heathy woodland on sandstone outcrops (south of Laura, Queensland) or coastal sands (north of Cooktown, Queensland). Prior to this study, very little material of *C. geminus* had been collected from the

Northern Territory (a total of 11 specimens (6 ♂, 5 ♀) from 1972–2007 are held in ANIC and QM), and it was previously known only from Kakadu National Park (Common and Waterhouse 1981). More recently, Braby (2011) reported the larval food plants from two locations in Kakadu and Nitmiluk National Parks, and discovered a new location at Wongalara Station based on material collected during a Bush Blitz expedition in 2012 (Braby 2012). Critical examination and comparison of this material has revealed that it is indeed conspecific with *C. geminus*, but that the population is taxonomically distinct according to the criteria proposed by Braby et al. (2012) for subspecies delimitation.

MATERIALS AND METHODS

Between 2007 and 2014, I conducted extensive field studies in the 'Top End' of the Northern Territory. Most of the major blocks of sandstone in this region (i.e., areas of potentially suitable habitat) were searched for presence of the butterfly (adults and/or immature stages), including Keep River-Spirit Hills National Park, Judbarra/Gregory National Park, Litchfield National Park, Limmen National Park and the Arnhem Land Plateau (Kakadu National Park, Nitmiluk National Park and Wongalara Wildlife Sanctuary). Searches were also conducted in the Kimberley region of Western Australia (Mitchell Plateau, Kalumburu, King Leopold Ranges, El Questro Wilderness Park, Purnululu National Park) and in western Queensland (Boodjamulla (Lawn Hill) National Park). Vines of the larval food plants (*Cassytha* spp.) were searched for the immature stages (eggs and larvae), which were reared on fresh cuttings of the food plant in captivity to adulthood in plastic containers.

The male genitalia of three specimens (from Kakadu and Nitmiluk National Parks, Northern Territory) were dissected, examined and compared with two specimens of *C. geminus* from eastern Australia (16 km SE of Hopevale, Queensland and Pilliga National Park, New South Wales). The genitalia were examined and compared by dissecting the terminal segments of the abdomen according to the method outlined in Braby (2000).

Adult size (both sexes) was compared with the nominate subspecies based on wingspan measurements. Wingspan was measured as the straight-line distance between the apices of each forewing of correctly spread specimens (i.e., in which the dorsum was set at right angles to the body) deposited in the ANIC using a digital calliper (K11100, Kincrome©) to an accuracy of one decimal place (0.1 mm). Approximately 60 specimens of each sex were sampled from the Northern Territory and across the species' geographical range in New South Wales/Queensland. For each specimen two measurements were made and an average of the two readings was taken. Franklin and Bisa (2008) have demonstrated that wingspan is positively and significantly correlated with forewing length, and thus it is a useful proxy of adult size. The wingspan data was analysed using 2-way ANOVA (with LOCATION (NT or QLD/NSW) and SEX (Male or Female) as the independent variables) to assess any differences in size between the putative taxa.

The immature stages were compared with the published descriptions of *C. geminus* given by Edwards (1980) and material reared from Davies Creek National Park, the Burra Range, Queensland and Pilliga Scrub, New South Wales by the author.

Material was examined in the following repositories:

ANIC:	Australian National Insect Collection, Canberra
QM:	Queensland Museum, Brisbane
NTM:	Museum and Art Gallery of the Northern Territory, Darwin

TAXONOMY

Family Lycaenidae Leach, 1815

Subfamily Theclinae Swainson, 1831

Tribe Candalidini Eliot, 1973

Genus *Candalides* Hübner, 1819

***Candalides* Hübner, 1819: 73.**

Rusticus xanthospilos Hübner, 1817 by subsequent designation of Scudder (1875).

Candalides geminus Edwards & Kerr, 1978

Candalides geminus gagadju ssp. nov.

Figures 5–8, 13, 14

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MATERIAL EXAMINED

Holotype

Australia: ***Northern Territory*:** ♂ '12.85463°S, 132.81677°E, Barrk Track, Nourlangie Rock, Kakadu NP, NT, 4 MAY 2008, MF Braby & LJ Aitchison' (ANIC).

Paratypes

Australia: ***Northern Territory*****:** 67 ♂, 62 ♀. 1 ♂ '12.31S 132.58E, 9 km N by E of Mudginbarry H.S., N.T. 30 Oct. 1972, IFB. Common, E.D. Edwards, MS. Upton' (ANIC); 1 ♀ '12.25S 132.58E, 1 km N of Cahills Crossing, East Alligator River, N.T. 31 Oct. 1972, IFB. Common, E.D. Edwards, MS. Upton' (ANIC); 1 ♀ '12.52S 132.50E, Koongarra, 15km E of Mt. Cahill, N.T., 8 Mar 1973, M.S. Upton' (ANIC); 2 ♀ '12.50S 132.51E, 15km NE of Mt. Cahill, N.T., 23 May 1973, E.D. Edwards & M.S. Upton' (ANIC); 1 ♂, 1 ♀ '12.31S 132.58E, 9km NE of Mudginbarry H.S., NT. 26 May 1973, E.D. Edwards & M.S. Upton' (ANIC); 1 ♂ 'N.T. 12.45S, 132.53E, Radon Ck. (openforest), 14-16 July 1979, G. Monteith & D. Cook' (ANIC); 1 ♂ '12.85701°S, 132.79053°E, Nawurlandja, Kakadu NP, NT, 160m, 28 JAN. 2007, M.F. Braby', 'genitalia 024' (ANIC); 1 ♂ '14.32032°S, 132.43723°E, Windolf Trail, Katherine Gorge, Nitmiluk NP, NT, 20 JUL. 2007, MF Braby & LJ Aitchison' (ANIC); 2 ♂, 1 ♀ '14.32032°S, 132.43723°E, Windolf Trail, Katherine Gorge, Nitmiluk NP, NT, 21 JUL. 2007, MF Braby & LJ Aitchison' (ANIC); 1 ♀ '14.32032°S, 132.43723°E, Windolf Trail, Katherine Gorge, Nitmiluk NP, NT, emg. 20 AUG. 2007, MF Braby & LJ Aitchison', 'Reared from early instar larva on *Cassytha filiformis*, coll. 21 JUL. 2007, pupated 8 AUG. 2007' (ANIC); 6 ♂ '14.32032°S, 132.43723°E, Windolf Trail, Katherine Gorge, Nitmiluk NP, NT, 16 AUG. 2007, M.F. Braby & I. Morris' (ANIC); 1 ♂ '14.32032°S, 132.43723°E, Windolf Trail, Katherine Gorge, Nitmiluk NP, NT, emg. 2 SEP. 2007, M.F. Braby & I. Morris', 'Reared from larva on *Cassytha filiformis,* coll. 16 AUG. 2007' (ANIC); 1 ♂ '14.32032°S, 132.43723°E, Windolf Trail, Katherine Gorge, Nitmiluk NP, NT, emg. 8 SEP. 2007, M.F. Braby & I. Morris', 'Reared from larva on *Cassytha filiformis,* coll. 16 AUG. 2007' (ANIC); 1 ♀ '14.32032°S, 132.43723°E, Windolf Trail, Katherine Gorge, Nitmiluk NP, NT, emg. 10 SEP. 2007, M.F. Braby & I. Morris', 'Reared from egg on *Cassytha filiformis,* coll. 16 AUG. 2007' (ANIC); 1 ♂ '14.32032°S, 132.43723°E, Windolf Trail, Katherine Gorge, Nitmiluk NP, NT, emg. SEP. 2007, M.F. Braby & I. Morris' (ANIC); 5 ♂, 2 ♀ '12.83696°S, 132.85626°E, Gubara Track carpark, Kakadu NP, NT, 5 MAY 2008, MF Braby & LJ Aitchison' (ANIC); 1 ♂ '12.83696°S, 132.85626°E, Gubara Track carpark, Kakadu NP, NT, emg. 20 MAY 2008, MF Braby & LJ Aitchison', 'Reared from larva on *Cassytha filiformis*, coll. 5 MAY 2008' (ANIC); 1 ♀ '12.83696°S, 132.85626°E, Gubara Track carpark, Kakadu NP, NT, emg. 24 MAY 2008, MF Braby & LJ Aitchison', Reared from larva on *Cassytha filiformis,* coll. 5 MAY 2008' (ANIC); 3 ♂, 7 ♀ '12.83696°S, 132.85626°E, Gubara Track carpark, Kakadu NP, NT, 30 JAN. 2009, MF Braby & LJ Aitchison' (ANIC); 1 ♂, 5 ♀ '12.83696°S, 132.85626°E, Gubara Track carpark, Kakadu NP, NT, 4 DEC. 2009, MF Braby & J Armstrong' (ANIC); 1 ♂ '12.83696°S, 132.85626°E, Gubara Track carpark, Kakadu NP, NT, emg. 22 DEC. 2009, MF Braby & J Armstrong', 'Reared from larva on *Cassytha filiformis,* coll. 4 DEC. 2009, pupated 13 DEC. 2009' (ANIC); 2 ♂, 1 ♀ '12.83696°S, 132.85626°E, Gubara Track carpark, Kakadu NP, NT, 26 JUN. 2011, M.F. Braby' (ANIC); 1 ♂ '12.83696°S, 132.85626°E, Gubara Track carpark, Kakadu NP, NT, emg. 14 JUL. 2011, M.F. Braby', 'Reared from larva on *Cassytha filiformis,* coll. 26 JUN. 2011' (ANIC); 4 ♂, 7 ♀ '12.85463°S, 132.81677°E, Barrk Track, Nourlangie Rock, Kakadu NP, NT, 4 MAY 2008, MF Braby & LJ Aitchison' (ANIC); 1 ♀ '12.85463°S, 132.81677°E, Barrk Track, Nourlangie Rock, Kakadu NP, NT, emg. 18 MAY 2008, MF Braby & LJ Aitchison', 'Reared from larva on *Cassytha filiformis,* coll. 4 MAY 2008' (ANIC); 1 ♀ '12.85463°S, 132.81677°E, Barrk Track, Nourlangie Rock, Kakadu NP, NT, emg. 19 MAY 2008, MF Braby & LJ Aitchison', 'Reared from larva on *Cassytha filiformis,* coll. 4 MAY 2008' (ANIC); 1 ♂ '12.85463°S, 132.81677°E, Barrk Track, Nourlangie Rock, Kakadu NP, NT, emg. 3 JUN. 2008, MF Braby & LJ Aitchison', 'Reared from egg on *Cassytha filiformis,* pupated 23 MAY 2008, coll. 4 MAY 2008' (ANIC); 2 ♂ '13.43089°S, 132.41837°E, Waterfall Ck, Gunlom, Kakadu NP, NT, 28 AUG. 2008, MF Braby & LJ Aitchison' (ANIC); 6 ♂, 10 ♀ '13.42880°S, 132.41779°E, Waterfall Ck, Gunlom, Kakadu NP, NT, 29 AUG. 2008, MF Braby & LJ Aitchison' (ANIC); 1 ♂ '13.42880°S, 132.41779°E, Waterfall Ck, Gunlom, Kakadu NP, NT, emg. 22 SEP. 2008, MF Braby & LJ Aitchison', 'Reared from instar I on *Cassytha filiformis,* coll. 29 AUG. 2008' (ANIC); 3 ♂, 1 ♀ '12.84375°S, 132.82558°E, 1 km ENE Nanguluwur, Kakadu NP, NT, 50 m, 31 JAN. 2009, MF Braby & LJ Aitchison' (ANIC); 1 ♂ '12.84375°S, 132.82558°E, 1 km ENE Nanguluwur, Kakadu NP, NT, 50 m, emg. 13 FEB. 2009, MF Braby & LJ Aitchison', 'Reared from larva on *Cassytha filiformis*, coll. 31 JAN. 2009' (ANIC); 1 ♀ '12.84375°S, 132.82558°E, 1 km ENE Nanguluwur, Kakadu NP, NT, 50 m, emg. 14 FEB. 2009, MF Braby & LJ Aitchison', 'Reared from larva on *Cassytha filiformis*, coll. 31 JAN. 2009' (ANIC); 1 ♀ '12.84375°S, 132.82558°E, 1 km ENE Nanguluwur, Kakadu NP, NT, 50 m, emg. 15 FEB. 2009, MF Braby & LJ Aitchison', 'Reared from larva on *Cassytha filiformis*, coll. 31 JAN. 2009' (ANIC); 1 ♂, 1 ♀ '12.84375°S, 132.82558°E, 1 km ENE Nanguluwur, Nourlangie

Rock, NT, 8 NOV. 2009, M.F. Braby' (ANIC); 1 ♂ '12.84375°S, 132.82558°E, 1 km ENE Nanguluwur, Nourlangie Rock, NT, emg. 22 NOV. 2009, M.F. Braby', 'Reared from larva on *Cassytha filiformis,* coll. 8 NOV. 2009' (ANIC); 1 ♀ '12.84650°S, 132.82295°E, Nourlangie Rock, Kakadu NP, NT, 120 m, 1 FEB. 2009, M.F. Braby & LJ Aitchison' (ANIC); 1 ♂ '12.84650°S, 132.82295°E, Nourlangie Rock, Kakadu NP, NT, 120 m, 8 NOV. 2009, M.F. Braby' (ANIC); 1 ♀ '12.84650°S, 132.82295°E, Nourlangie Rock, Kakadu NP, NT, emg. 9 FEB. 2014, MF Braby & LJ Aitchison', 'Reared from larva on *Cassytha filiformis,* coll. 26 JAN. 2014' (ANIC); 1 ♂, 1 ♀ '12.84650°S, 132.82295°E, 0.6 km E Nanguluwur, Kakadu NP, NT, 120m, 5 DEC. 2009, MF Braby & J Armstrong' (ANIC); 1 ♂ '12.84650°S, 132.82295°E, 0.6 km E Nanguluwur, Kakadu NP, NT, 120m, 5 DEC. 2009, MF Braby & J Armstrong', 'genitalia 051' (ANIC); 2 ♀ '12.84650°S, 132.82295°E, 0.6 km E Nanguluwur, Kakadu NP, NT, 120m, 7 DEC. 2009, MF Braby & J Armstrong' (ANIC); 1 ♀ '12.84650°S, 132.82295°E, 0.6 km E Nanguluwur, Kakadu NP, NT, 15 FEB. 2013, MF Braby' (ANIC); 1 ♀ '12.83721°S, 132.84970°E, 0.6 km W Gubara Tk carprk, Kakadu NP, NT, 16 OCT. 2010, M.F. Braby & S. Keates' (ANIC); 1 ♀ '12.83721°S, 132.84970°E, 0.6 km W Gubara Tk carprk, Kakadu NP, NT, emg. 26 NOV. 2010, M.F. Braby', 'Reared from larva on *Cassytha filiformis,* coll. 12 NOV. 2010' (ANIC); 1 ♀ '13.20353°S, 130.71574°E, Tolmer Falls, Litchfield NP, NT, 28 APR. 2011, MF Braby & JJ Armstrong' (ANIC); 4 ♂, 2 ♀ '13.19495°S, 130.70848°E, 1 km NW of Tolmer Falls, Litchfield NP, NT, 9 JUL. 2011, M.F. Braby & S. Keates' (ANIC); 1 ♂ '13.19495°S, 130.70848°E, 1 km NW of Tolmer Falls, Litchfield NP, NT, emg. 11 AUG. 2011, M.F. Braby & S. Keates', 'Reared from egg on *Cassytha capillaris,* coll. 9 JUL. 2011' (ANIC); 1 ♀ '13.19495°S, 130.70848°E, 1 km NW of Tolmer Falls, Litchfield NP, NT, emg. 12 AUG. 2011, M.F. Braby & S. Keates', 'Reared from egg on *Cassytha capillaris,* coll. 9 JUL. 2011' (ANIC); 3 ♂ '14.25149°S, 134.46429°E, 12 km S of H/S Wongalara WS, NT, 29 MAY 2012, M.F. Braby & R. Leijs' (ANIC); 1 ♀ '14.25149°S, 134.46429°E, 12 km S of H/S Wongalara WS, NT, 29 MAY 2012, M.F. Braby & R. Leijs' (NTM); 1 ♂ '14.25149°S, 134.46429°E, 12 km S of H/S Wongalara WS, NT, 5 JUN. 2012, M.F. Braby' (NTM); 4 ♂, 1 ♀ '14.25149°S, 134.46429°E, 12 km S of H/S Wongalara WS, NT, 5 JUN. 2012, M.F. Braby' (ANIC); 1 ♂ '14.16221°S, 134.12724°E, Mt Throsby, Wongalara WS, NT, emg. 26 JUN. 2012, M.F. Braby', 'Reared from larva on *Cassytha filiformis,* coll. 30 MAY 2012' (ANIC); 1 ♀ '14.16221°S, 134.12724°E, Mt Throsby, Wongalara WS, NT, emg. 14 JUL. 2012, M.F. Braby', 'Reared from egg on *Cassytha filiformis,* coll. 30 MAY 2012' (ANIC).

Other material

Australia: ***Northern Territory*****:** 3 ♂ 'N.T. 12.45S, 132.53E, Radon Ck. (openforest), 14-16 July 1979, G. Monteith & D. Cook' (QM); 1 ♀ '13°25'43'S, 132°25'06'E, Gunlom, Kakadu NP, NT, 6 MAY 2007, L. Reid' (ANIC); 2 ♂ '14.32032°S, 132.43723°E, Windolf Trail, Katherine Gorge, Nitmiluk NP, NT, 16 AUG. 2007, M.F. Braby & I. Morris' (ANIC); 3 ♀ '14.32032°S, 132.43723°E, Windolf Trail, Katherine Gorge, Nitmiluk NP, NT, 20 JUL. 2007, MF Braby & LJ Aitchison' (ANIC); 1 ♂ '14.32032°S, 132.43723°E, Windolf Trail, Katherine Gorge, Nitmiluk NP, NT, 20 JUL. 2007, MF Braby & LJ Aitchison', 'genitalia 039' (ANIC); 1 ♂ '14.32032°S, 132.43723°E, Windolf Trail, Katherine Gorge, Nitmiluk NP, NT, 21 JUL. 2007, MF Braby & LJ Aitchison' (ANIC); 1 ♂ '12.85463°S, 132.81677°E, Barrk Track, Nourlangie Rock, Kakadu NP, NT, 4 MAY 2008, MF Braby & LJ Aitchison' (ANIC); 1 ♀ '13.20353°S, 130.71574°E, Tolmer Falls,

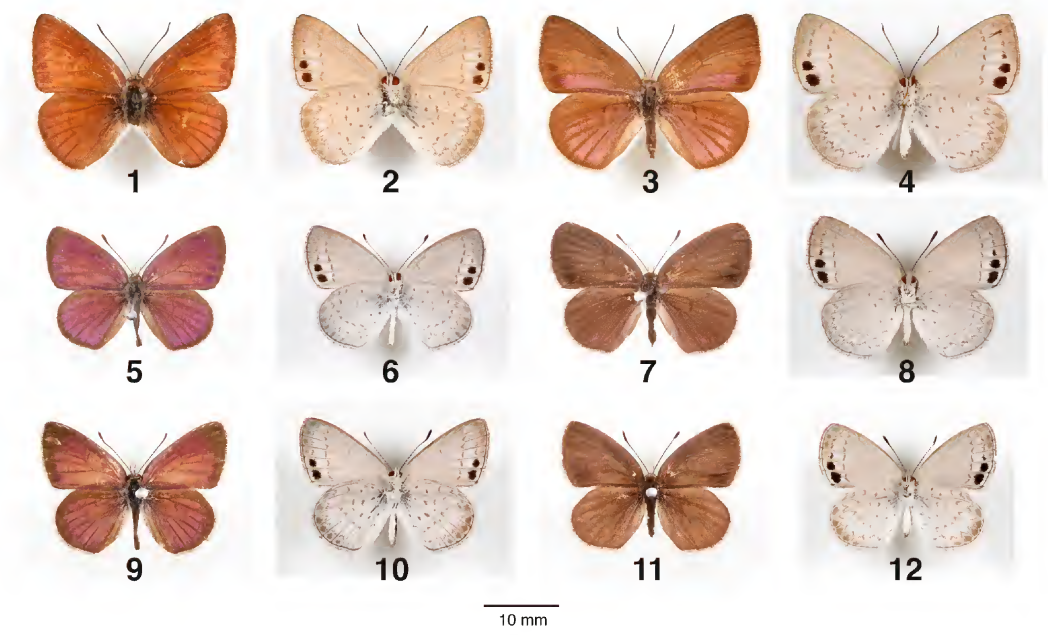
TABLE 1 Wingspan measurements for *Candalides geminus* subspecies. Two-way ANOVA (with LOCATION and SEX as the independent variables) revealed significant differences in wing size between the two taxa (F=454.3, df = 235, P<0.0001), but no differences between the sexes within each subspecies (P>0.01).

Subspecies	Location	Sex	Range	Mean ± SD	n
C. g. gagadju	NT	male	17.6–24.8	21.19 ± 1.455	60
C. g. gagadju	NT	female	18.2–24.6	21.72 ± 1.459	57
C. g. geminus	QLD/NSW	male	22.2–28.9	25.27 ± 1.488	60
C. g. geminus	QLD/NSW	female	22.1–31.2	25.92 ± 1.487	60

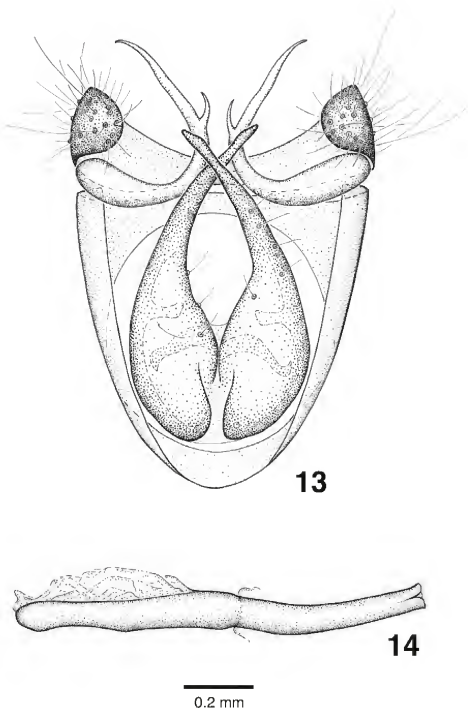
Litchfield NP, NT, 28 APR. 2011, MF Braby & JJ Armstrong' (ANIC); 1 ♂ '13.19495°S, 130.70848°E, 1 km NW of Tolmer Falls, Litchfield NP, NT, 9 JUL. 2011, M.F. Braby & S. Keates' (ANIC).

DIAGNOSIS

Candalides geminus gagadju (Figures 5–8) differs from the nominate subspecies *C. geminus geminus* (Figures 1–4) by the following four phenotypic characters: (1) adults are significantly smaller in size (Table 1); (2) the termen of the wings, particularly the forewing, is more rounded with the apex less sharply pointed, especially males; (3) the upperside colour of females is uniformly dark grey-brown with the basal and central iridescent purple areas either absent (50% of specimens examined, $n = 60$) or substantially reduced to two small subterminal 'patches' of purple scales on the hindwing (between veins CuA_1 and 1A+2A), whereas in *C. geminus geminus* the purple area, although variable in extent, is always present and far more extensive; and (4) the shape described by the postmedian line of spots on the underside of the hindwing is both generally more concave and displaced distally towards the subterminal line of spots so that the postmedian band (the intervening area between these two lines) is narrower and often a paler grey compared to the rest of the underside ground colour. The underside ground colour of *C. geminus gagadju*, like that of *C. geminus geminus*, is grey, although populations of *C. geminus geminus* from the southern



FIGURES 1–12 Adult specimens of *Candalides* spp. 1, 2, *C. geminus geminus* holotype male showing dorsal and ventral views [labelled 'Captain Billy Creek, Cape York Pen, N. Qld, 142°50E, 11°45S, 12–14.vii.1975, J.F.R. Kerr', 'Genitalia Slide M347' (ANIC)]; 3, 4, *C. geminus geminus* paratype female showing dorsal and ventral views [labelled same as holotype (ANIC)]; 5, 6, *C. geminus gagadju* ssp. nov. male holotype showing dorsal and ventral views [labelled '12.85463°S, 132.81677°E, Barrk Track, Nourlangie Rock, Kakadu NP, NT, 4 MAY 2008, MF Braby & LJ Aitchison' (ANIC)]; 7, *C. geminus gagadju* paratype female dorsal view [labeled '12.83696°S, 132.85626°E, Gubara Track carpark, Kakadu NP, NT, emg. 24 MAY 2008, MF Braby & LJ Aitchison, Reared from larva on *Cassytha filiformis*, coll. 5 MAY 2008' (ANIC)]; 8, *C. geminus gagadju* paratype female ventral view [labelled '12.84375°S, 132.82558°E, 1 km ENE Nanguluwur, Nourlangie Rock, NT, 8 NOV. 2009, M.F. Braby' (ANIC)]; 9, 10, *C. erinus erinus* male showing dorsal and ventral views [labelled '12.85930°S, 132.81754°E, Nourlangie Rock, Kakadu NP, NT, 4 MAY 2008, MF Braby & LJ Aitchison, MFB Collection 00369' (ANIC)]; 11, 12, *C. erinus erinus* female showing dorsal and ventral views [labelled '12.29586°S, 136.90302°E, Rocky Bay, Gove Peninsula, NT, 1 SEP. 2007, M.F. Braby, MFB Collection 00369' (ANIC)].



FIGURES 13–14 Male genitalia of *Candalides geminus gagadju* ssp. nov. 13, posterior view showing valvae and brachia, with phallus removed; 14, phallus, lateral view.

end of the range (Pilliga Scrub, Warrumbungle Ranges, and near Dubbo, New South Wales) differ in having the colour dark brownish-grey with the underside markings less distinct and the terminal blotches on the hindwing absent.

In many respects, *C. geminus gagadju* more closely resembles *C. erinus* (Fabricius, 1775) (Figures 9–12) from northern Australia in size, shape and colour pattern than *C. geminus geminus*. However, in *C. erinus* the postmedian band and dark grey terminal blotches on the underside of the hindwing are more distinct. In *C. erinus*, the postmedian band is both broader, with a straighter inner edge, and paler so that it contrasts against the grey ground colour, whereas in *C. geminus gagadju* the postmedian band is narrower, with the inner edge distinctly curved, and less contrasted. In males, the black terminal band or margin on the upperside of the forewing is broader towards the apex in *C. erinus*, whereas in *C. geminus gagadju* the band is narrower and even in width parallel to the termen. Also, the male genitalia of *C. geminus gagadju* (Figures 13–14) differ considerably from *C. erinus*, but are typical of *C. geminus* in which the valvae gradually taper towards the apex (see comparative illustrations in Edwards and Kerr 1978, p. 85). In *C. erinus*, the valvae are very and long slender and do not taper from the swollen base.

DESCRIPTION

Male. Forewing length 12.4 mm (holotype, Figures 5–6), range 10.5–14.4 mm. Upperside colour purplish-bronze, with narrow black margins. Underside ground colour pale grey, with a series of small darker grey spots and markings; forewing with a postmedian line of spots extending from costa to dorsum, a line of three subterminal spots from costa to vein M_3, an obscure black subterminal spot between veins M_3 and CuA_1, and two larger prominent black subterminal spots near tornus between veins CuA_1 and 1A+2A, each surrounded by a pale grey-white area that extends proximally to postmedian line; hindwing with a narrow paler postmedian band edged proximally by a series of darker spots and distally by a subterminal series of spots, followed by a series of larger obscure dark grey terminal blotches.

Female. Forewing length 12.6–14.1 mm (paratypes, Figures 7–8), range 10.8–14.6 mm. Upperside brown-black; forewing with two black subterminal spots near tornus; hindwing often with two small purple subterminal patches between veins CuA_1 and 1A+2A. Underside colour and pattern similar to male.

VARIATION

In males, the upperside colour varies from dull bronze-purple to shining purple, with examples of the latter form collected or reared mainly during the cooler dry season months (May–August) suggesting that there may be a seasonal component to the variation.

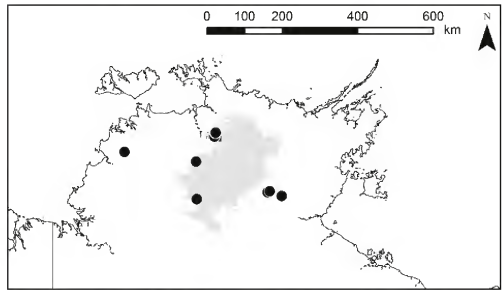
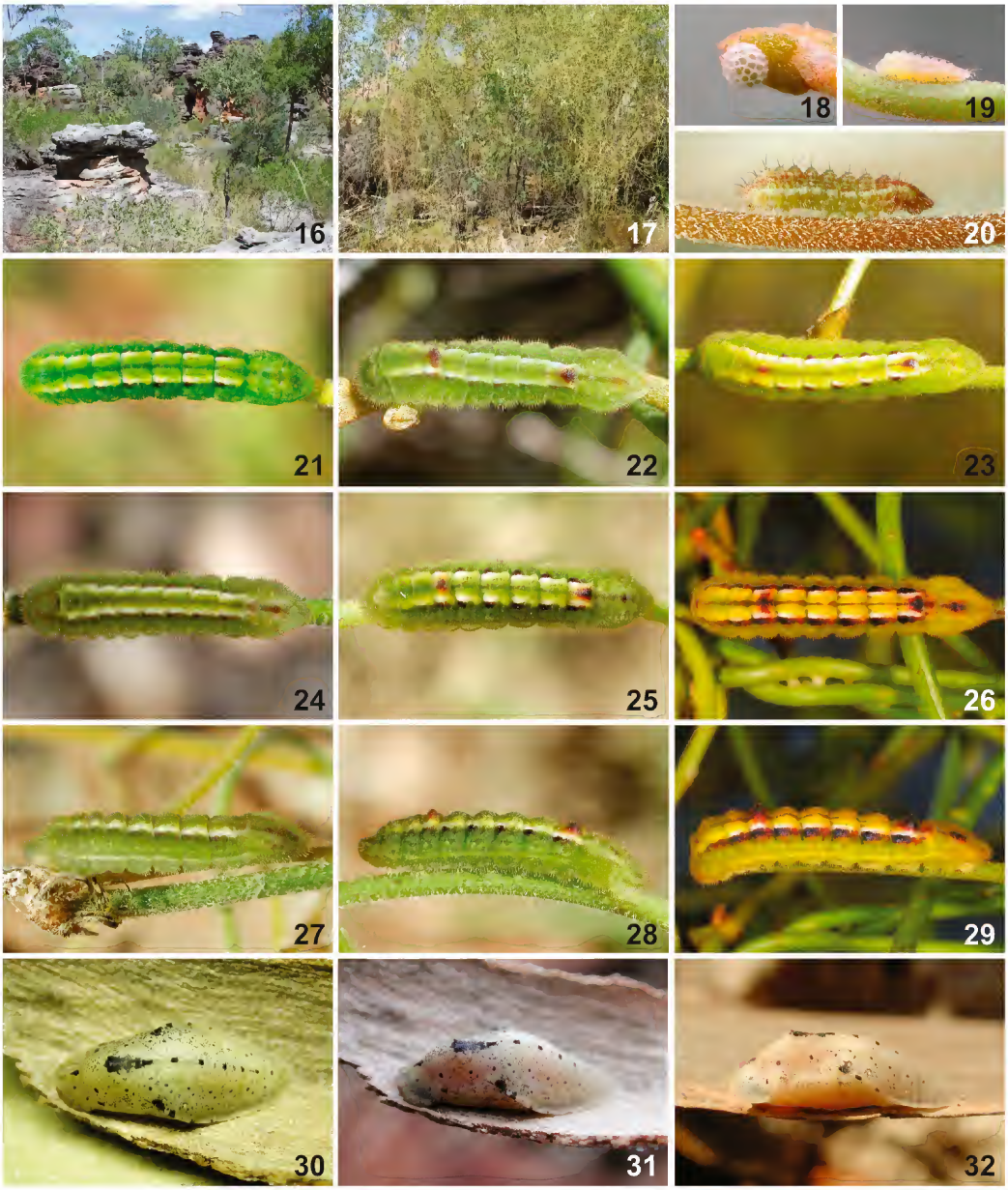


FIGURE 15 Distribution of *Candalides geminus gagadju* in the Top End of the Northern Territory. Grey shaded polygon shows extent of the Arnhem Land plateau.



FIGURES 16–32 Life history of *Candalides geminus gagadju*. 16, eucalypt heathy open-woodland habitat on broken sandstone at Nourlangie Rock, Kakadu National Park; 17, larval food plant *Cassytha filiformis* at Windolf Trail, Nitmiluk (Katherine Gorge) National Park; 18, egg; 19, first instar larva; 20, second instar larva; 21–29, final instar larva, showing phenotypic variation, 21–26, dorsal view, 27–29, lateral view; 30–32, pupa, showing dorsal, dorsolateral and lateral views.

The width of the black margin also varies. In females, the extent of the purple iridescent areas varies: when present, it is usually restricted to the subterminal region of the hindwing (comprising two small patches), but in cell 1A+2A it may extend towards the base, and occasionally a third subterminal patch occurs between veins M_3 and CuA_1; very occasionally there may be a dusting of purple scales at the base of the forewing, usually just above the dorsum. In both sexes, there is considerable variation in the extent and clarity of the underside markings, particularly the postmedian and subterminal series of spots, which may be very obscure in some specimens.

REMARKS

Edwards and Kerr (1978) described and illustrated *C. geminus,* which had previously been confused with the closely-related *C. hyacinthinus* (Semper), as a monotypic species from eastern Australia, with type locality Captain Billy Creek, Cape York Peninsula, Queensland. However, material from the Top End of the Northern Territory was not included in their description and diagnosis. Although specimens of *C. geminus gagadju* (2 ♂, 5 ♀ in ANIC) were first collected from western Arnhem Land in 1972–73 by I.F.B. Common, E.D. Edwards and M.S. Upton, this material was not considered in the description and distribution of *C. geminus* because it had been misidentified and confused with *C. erinus* (E.D. Edwards, pers. comm., 2017). The first published record of *C. geminus* from the Top End was the report by Kikkawa and Monteith (1980), who recorded the species based on a small series (4 ♂ in QM and ANIC) from Radon Creek on the Arnhem Land plateau in 1979.

The systematic relationships of the *C. erinus* species group have not been established, but a preliminary molecular phylogenetic analysis of the Candalidini indicates that *C. geminus* and *C. erinus* are sister taxa and are genetically divergent by 2.7% for mitochondrial COI (24 bp differences out of 880 bp for the barcode region) under the HKY substitution model, whereas the distance between the two subspecies of *C. geminus* for this region is 1.7% or 15 bp (M. Espeland and M.F. Braby, unpublished data).

ETYMOLOGY

The name Gagadju is the language name for the Australian Aboriginal tribe from western Arnhem Land in the Northern Territory where this butterfly is predominantly distributed. The name has several variations in spelling (e.g. Gagadu, Kakadju, Kakadu and Kakatu), but Gagadju is the name adopted here. It is intended as a noun in apposition.

DISTRIBUTION

Candalides geminus gagadju is endemic to the Top End of the Northern Territory where it has been recorded from Litchfield National Park (Tolmer Falls area), Kakadu National Park (including Nourlangie Rock and Gunlom), Nitmiluk (Katherine Gorge) National Park and Wongalara Wildlife Sanctuary. The distribution is centred mainly on the Arnhem Land plateau (Figure 15), although there is a disjunct population 200 km further west in Litchfield National Park. Searches for the taxon in the sandstone areas of the Kimberley region of Western Australia, Keep River-Spirit Hills, Judbarra/Gregory and Limmen national parks in the Northern Territory, and Boodjamulla (Lawn Hill) National Park in western Queensland by the author, did not detect the subspecies. *Candalides geminus gagadju* frequently occurs in sympatry with *C. erinus*, and at Wongalara Wildlife Sanctuary (12 km S of the homestead) it was recorded in sympatry with both *C. erinus* and *C. delospila* (Waterhouse, 1903).

BIOLOGY

Candalides geminus gagadju is restricted to blocks of sandstone in the higher rainfall areas (>900 mm mean annual rainfall) of the Northern Territory where it breeds in eucalypt heathy woodland and open-woodland with a spinifex understorey on rocky sandstone outcrops, escarpments and plateaus where the larval food plants grow as scrambling parasitic vines in the understorey (Figures 16–17) (Braby 2011). The usual larval food plant is *Cassytha filiformis* L. (Lauraceae), but *C. capillaris* Meisn. is also used where it is present (Braby 2011). Adults have been recorded during most months of the year, but they appear to be more abundant during the wet season (November–January) and in the mid dry season (July).

The immature stages (egg, larva and pupa) (Figures 18–32) are identical to those of *C. geminus geminus*, which were described by Edwards (1980). A feature distinguishing *C. geminus* from other *Candalides* spp. is the colour pattern of the final instar larva, which is characterised by a prominent white subdorsal line on abdominal segments 1 to 6 that is bordered laterally by a deep purple line, and the presence of two raised, red dorsal projections, on abdominal segments 1 and 6. The white subdorsal line extends to the mesothorax and metathorax, where it usually becomes pale yellow, and on the abdomen it may become yellow towards the rear of each segment. Larvae of *C. geminus gagadju* (Figures 21–29) possess these two characters, but they are highly variable in colour pattern, particularly with respect to the overall ground colour (which comprises various shades of green); the presence of the raised, red dorsal projections on abdominal segments 1 and 6

(the projections are usually present, but occasionally both may be absent, Figures 21, 24, 27); and the extent and clarity of the purple subdorsal line, which may comprise a continuous narrow band (Figures 22, 24, 27), a broken band of discrete spots (Figures 21, 23, 25, 28), or a continuous broad band edged posteriorly with bright red (Figures 26, 29). The immature stages have been recorded in most months of the year. The life cycle is completed relatively quickly (approximately one month, with the larval duration varying from 14–18 days and pupal duration 11–12 days), indicating that breeding occurs continuously and that several generations are completed annually.

ACKNOWLEDGEMENTS

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Fossil mammals of Caladenia Cave, northern Swan Coastal Plain, south-western Australia

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ABSTRACT – Quaternary palaeoecological research in Western Australia has been focussed primarily around Perth and the extreme south-west, with very little work conducted to the north between 29° and 32°S. Using fossil remains excavated in the 1970s from Caladenia Cave in the East Moore cave area of the northern Swan Coastal Plain, we sought evidence of compositional change in the regional mammal fauna from the mid-Holocene to the present. Loss of *Phascogale calura*, *Perameles bougainville* and *Lagorchestes hirsutus*, species characteristic of semi-arid and arid regions, suggests an increase in rainfall from around 4700 cal. BP. A change to a smaller sieve mesh aperture in the deepest levels of the excavation caused differential recovery which constrained the extent to which ecological inferences could be made. This bias notwithstanding, the Caladenia Cave assemblage suggests major community changes did not characterise the late Holocene, indicating resilience to the impacts of environmental changes prior to European settlement.

KEYWORDS: Holocene, Palaeoecology, Differential Recovery, EM-17

INTRODUCTION

Western Australian vertebrate palaeontology was focussed primarily on the documentation of megafaunal remains until the visit in the mid 1950s by American Fulbright Scholar Ernest L. Lundelius Jr, who initiated the palaeoecological investigation of small mammal assemblages (Lundelius 1957, 1960). Many Western Australian Quaternary cave deposits provide evidence of climatically-driven changes in Late Quaternary species distributions and abundances (Lundelius 1960; Merrilees 1967). Quantitative analyses of small mammal accumulations can provide a more accurate representation of the original communities surrounding a deposit than historical records (Baynes 1979; Lundelius 2006).

Previous studies in south-western Australia have interpreted patterns in climate change from presence/absence and abundance of 'proxy' species over time (Baynes et al. 1976; Balme et al. 1978; Prideaux et al. 2010). Species such as *Perameles bougainville*, *Bettongia lesueur* and *Petrogale lateralis* are considered indicative of a drier, non-forest environment (Merrilees 1967), whereas *Setonix brachyurus* is considered a proxy for a dense understorey of tall karri forest that requires an annual rainfall of 1000–1200 mm (Baynes et al. 1976; Dortch 2004; Prideaux et al. 2010). These examples demonstrate that changes in climate can be inferred from change in the presence/absence of species characteristic of ecosystems adapted to higher or lower rainfall (see Dortch 2004).

There are very few early historic records of mammals of the northern Swan Coastal Plain, most of the native populations having been devastated by the introduction of cats, foxes and rabbits (see Kitchener et al. 1978 and Wilson et al. 2012). Consequently, fossil assemblages offer the best archives of fauna that originally occupied the region. The study of palaeontological assemblages can generate data that may help model the impacts that future anthropogenic climate change may have

on endemic fauna. Similar work in northern Western Australia and South Australia using Holocene cave sites has been used to extend species records for conservation research in national parks and suggested species rehabilitation sites based on palaeo-distributions (Baynes and McDowell 2010; McDowell et al. 2012). Our investigation of the Caladenia Cave fossil mammal assemblage in 2013 tracked the presence/absence and relative abundances of mammal species through time to detect correlations with extrinsic factors such as climate change. At conception, the investigation was purely exploratory and no hypothesis could be proposed about the presence of particular fauna, or any palaeoecological signals within the resulting data.

SITE

Caladenia Cave (EM-17) is located between the Moore River mouth at Guilderton and Gingin Scarp on the Swan Coastal Plain (Figure 1). It is one of 19 caves known in the East Moore cave area and the only cave excavated for vertebrate remains (Susac 2007). Caladenia Cave is an inclined fissure cave that developed in the Tamala Limestone, a Pleistocene aeolian calcarenite (Bastian 1964).

The discovery of vertebrate remains and their subsequent excavation in Caladenia Cave by amateur palaeontologist Robin Roe in the early 1970s provides the only existing late Quaternary record in the lower Moore River catchment. As Roe's trench was backfilled its precise location could not be determined. However, based on sketches in Roe's notebook (Roe 1971) we were able to determine its approximate location (Figures 2–3).

MATERIALS AND METHODS

SOURCING THE MATERIAL

The fieldwork and excavation conducted by Robin Roe (1970–1975) was initially supervised by Duncan Merrilees (1970–1972), Curator of Palaeontology at the Western Australian Museum, and later assisted by Sandra Sofoulis (1972 until completion). During excavation, Roe and Sofoulis noticed a deterioration of material condition at greater depths and changed the sieve grade to mitigate loss of small specimens (Roe 1974). They used sieves with 3 mm mesh aperture to sieve the sediment from the surface of the deposit down to the base of 'Stone Heap End' and the test pit. For 'Wall End' they changed to a sieve with a 1 mm mesh from 1.48 m to 2.54 m (Groups L to R). Rock and other materials not relevant to the investigation were removed by Roe after sieving. The screen residues were sorted and preliminarily identified by R. P. Hart, K. A. Lance, D. Merrilees and J. K. Porter in the 1970s. Bone specimens were placed in labelled 6 or 12 dram vials and stored by excavation spit. Bird, reptile, fish and archaeological materials were not further investigated in this study.

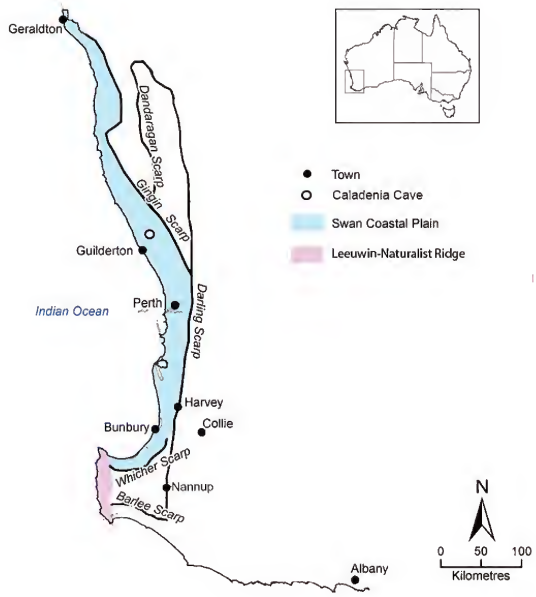

FIGURE 1 Map of the geomorphological features of the southern west coastal region of Australia, showing the location of Caladenia Cave. Image adapted from Barron et al. (2012).

Taphonomic analyses were based on the unidentified bulk-bone fragments, chosen randomly from each data Group (see Table 1) and examined for breakage and digestion damage. Evidence for digestion was recorded as an estimated percentage of the bone surface showing digestive erosion. Breakage was recorded as the percentage remaining of the original complete bone. Material was divided into two faunal size classes (mean adult body weight >250 g and <250 g) to ensure that sieve size bias could be removed from at least the larger species data set. The data were subjected to a Shapiro-Wilk test for normality within each size class. Paired *t*-tests were then conducted in PAST to determine if the two size classes were taphonomically different from one another.

Caladenia Cave was surveyed and mapped in 2013 at grade 44 of the Australian Speleological Federation survey and map standards (Anderson 1997), with width and height measurements recorded every 1 m along the N–S and E–W sections, accurate to the nearest 0.1 m.

CHRONOLOGY

Charcoal samples were collected from most spits, wrapped in foil, labelled and bagged by Roe at the time of excavation. In 2013 samples for dating were chosen based on significant fauna-related events, such as the disappearance of species from the assemblage, or at major stratigraphic boundaries, and at the base and close

to the surface of the deposit, to date the length of the period of accumulation. No charcoal was available above a depth of 700 mm and samples below 2230 mm were contaminated with disturbed material. The charcoal samples were removed from the foil, weighed on an electronic scale, placed in individual polythene bags, and designated a sample number to be sent to Waikato University Radiocarbon Dating Laboratory for dating (liquid scintillation counting).

Another of Roe's charcoal samples was added to resolve an inconsistency within the first group of dates. The small size of the charcoal sample meant that this had to be dated using accelerated mass spectrometry (AMS). Results are *Conventional Age* or *Percent Modern Carbon (pMC),* following Stuiver and Polach (1977). All material dated from Caladenia Cave was calibrated with OxCal, using the SHCal13 Southern Hemisphere calibration curve (Bronk Ramsey 2009; Bronk Ramsey and Lee 2013; Hogg et al. 2013).

IDENTIFICATION OF MAMMALS

Species nomenclature follows Van Dyck and Strahan (2008) except for the Macropodidae and Rodentia for which taxonomy follows Prideaux and Warburton (2010) and Aplin (2006), respectively. Mammal remains were identified to the lowest taxonomic level possible using museum specimens and published descriptions for comparison. Attempts were made to distinguish between species of *Sminthopsis* using characteristics reported by Archer (1981) and Kitchener et al. (1984). Rodents were identified according to the characteristics reported in Appendix III of Baynes (1979) and his other unpublished notes.

Cranio-dental elements of all mammals were identified. Post-cranial bones (calcanei, humeri, ulnae, femora, scapulae and pelvic elements) of larger mammals (>250 g) were also identified, using the Western Australian Museum fossil reference collection.

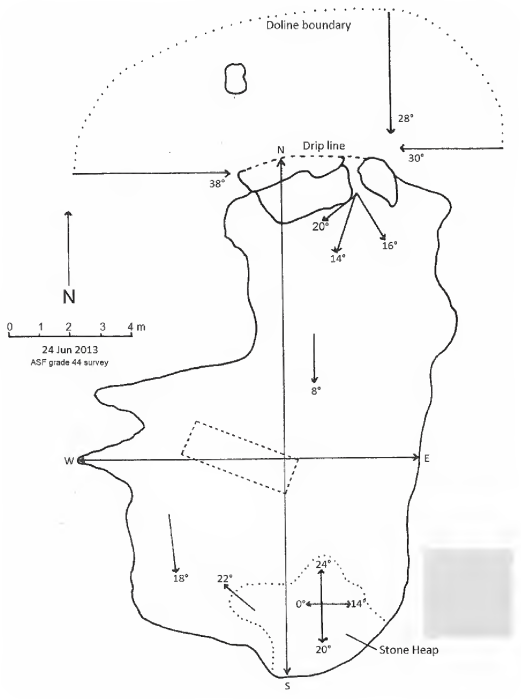

FIGURE 2 Plan view of Caladenia Cave. Angles refer to the direction and slope of the floor. Dashed rectangle indicates the approximate position of Roe's trench.

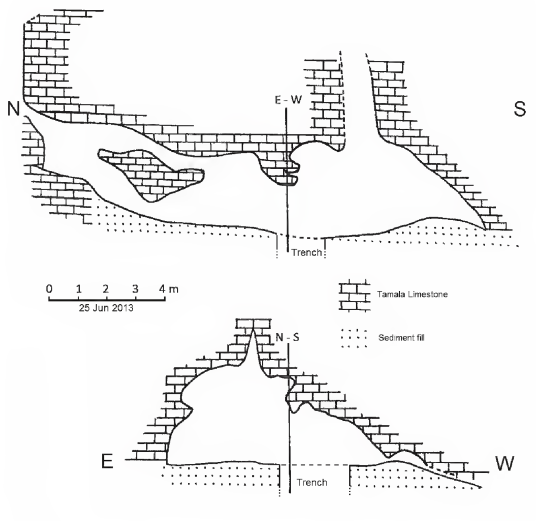

FIGURE 3 Longitudinal and transverse sections of Caladenia Cave. The north-south longitudinal section shows the entrance and edge of the doline on the left. The 'island' of limestone between the roof and floor of the cave is a collapsed part of roof and wall protruding into the section. The entrance slope is supported by large limestone boulders with unknown depths below the surface. The sections show the probable location of the trench inferred from Roe (1971). The protruding section of the ceiling visible in both diagrams is not speleothem development but where part of the ceiling has collapsed leaving an overhang.

TABLE 1 Designated data Groups used in statistical analyses, selected on the sieve size used and the sediment type recorded during excavation. In Groups A–C all spits were originally measured in inches before metric conversion. Surface was 270 mm below the datum. Depth measurements which overlap are due to stratigraphic dip and locations in the three named pit sections ('Stone heap end', test pit and 'Wall end'). The lime-flecked units are from the slumped stratigraphy, some of which was 'disturbed' and so measurements do not reflect the entire slump. The 3 mm sieve Groups I–K from 'Stone Heap End' and the test pit cover the depths also recorded in Groups L–R from 'Wall End'. Spits from 2100–2360 mm are disturbed samples and were excluded. 'Mixed-colour' sediments were not marked in Merrilees' section drawings, but were separated from other spits by Roe and so have been placed in a different Group.

Group	Sieve used	Top of unit (mm)	Base of unit (mm)	Stratigraphic unit	NISP
A	3 mm	270	524	Banded orange and brown sediments	728
B	3 mm	524	625.6	Banded orange and brown sediments	776
C	3 mm	625.6	752.6	Banded orange and brown sediments	737
D	3 mm	755	1050	Brown sediment (1)	672
E	3 mm	1045	1100	Dark brown sediment	537
F	3 mm	1100	1200	Brown sediment (2)	681
G	3 mm	1180	1510	Medium-grained orange sediment	1047
H	3 mm	1290	1340	Light brown bands	61
I	3 mm	1390	1560	Lime-flecked sediment	180
J	3 mm	1540	1980	Mixed colour sediment	227
K	3 mm	1635	2420	Brown sediment (3)	79
L	1 mm	1480	1600	Lime-flecked sediment	773
M	1 mm	1600	1660	Brown sediment (3)	680
N	1 mm	1660	1720	Brown sediment (3)	717
O	1 mm	1720	1840	Brown sediment (3)	767
P	1 mm	1840	1960	Brown sediment (3)	730
Q	1 mm	1960	2100	Brown sediment (3)	644
R	1 mm	2360	2500	Brown sediment (3)	413

TABLE 2 Radiocarbon dates generated by Waikato University Radiocarbon Dating Laboratory from charcoal samples collected during the 1970s Caladenia Cave excavations. The sample codes correspond to Caladenia Cave (CC) and the average depth of the source spit in centimetres (as originally recorded).

Sample code	Depth (mm)	Group	Waikato code	Radiocarbon age (BP)	Calibrated age (cal. BP)
CC100	1000	D	WK37157	2803 ± 68	3037–2750
CC108	1080	E	WK37158	2986 ± 58	3254–2925
CC137	1370	G	WK37159	3544 ± 43	3895–3641
CC154	1540	J	WK37160	3812 ± 45	4296–3979
CC160	1600	J	WK37161	4256 ± 56	4868–4569
CC223	2230	K	WK38730	1346 ± 20	1280–1180
CC231	2310	K	WK37162	1556 ± 34	1489–1316

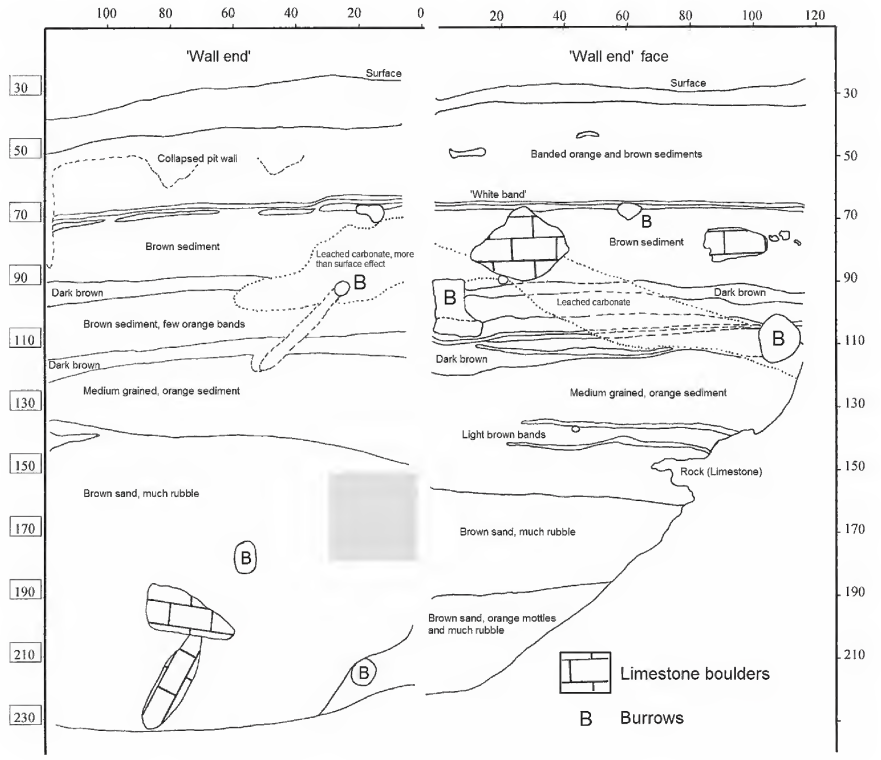

FIGURE 4 Section drawings of 'Wall end' and 'Wall end face', perpendicular faces of the trench. The 0 horizontal point denotes the NW corner of the trench and the datum from which section lines were measured. Burrows in the stratigraphy were either in-filled or contained small frogs. All material from the burrows was labelled disturbed (Roe 1971). All sections were originally sketched by D. Merrilees and redrawn and digitised for this investigation. Illustrations of the other sections are provided in Appendix 2.

PALAEOECOLOGY

Number of Identified Specimens (NISP) was chosen over the Minimum Number of Individuals as the preferred quantitative unit because it is a more robust measure of taxon abundance (Lyman 2008). NISP was calculated by counting all identified specimens (e.g. left and right dentaries and maxillae, and post-cranial material where identified, see Table 3). However, when edentulous jaws were present, isolated teeth were only counted after teeth corresponding to empty alveoli had been subtracted. Data were combined into Groups designated A–R (see Table 1 for details) based on their stratigraphic position, the sieve size used and to ensure sample sizes were robust enough for statistical analyses. Rarefaction curves were generated for each Group (A–R) using PAST (Hammer et al. 2001), to assess the likelihood that additional specimens would yield additional species (Gotelli and Colwell 2001; Hammer et al. 2001; Lyman and Ames 2007; Hammer and Harper 2008). Correspondence analysis was used to visualise patterns of species abundances in the assemblage.

Body mass statistics were sourced from Van Dyck and Strahan (2008) and the averages were calculated to separate the species into weight classes by 50 g steps. Relative abundance (Ri%) was calculated (NISPspecies/NISPtotal x 100) to elucidate quantitative differences between Groups. Changes in species diversity between Groups were assessed using the Simpson index of diversity ($1 - \lambda = 1 - \Sigma p_i^2$), which was calculated for both the full fauna and the fauna that remained after the <50 g species were removed, for comparison. Species <50g were subtracted from all Groups as many were differentially recovered by the 1 mm sieve. Each analysis was conducted in PAST and graphed in Excel. Species habitat guilds were generated from references shown in Table A1, Appendix 1.

TABLE 3 Number of Identified Specimens (NISP) from the Roe excavation in Caladenia Cave, listed by sieve size (3 mm and 1 mm), stratigraphy, Groups, and species.

		Group	*Thylacinus cynocephalus*	*Antechinus flavipes*	*Dasyurus geoffroii*	*Parantechinus apicalis*	*Phascogale calura*	*Phascogale tapoatafa*	*Sarcophilus harrisii*	*Sminthopsis* sp. indet	*Isoodon obesulus*	*Perameles bougainville*	*Cercartetus concinnus*	*Pseudocheirus occidentalis*	*Trichosurus vulpecula*	*Bettongia lesueur*	*Bettongia penicillata*	*Potorous platyops*	*Lagorchestes hirsutus*	*Macropus eugenii*	*Macropus fuliginosus*	*Macropus irma*	*Setonix brachyurus*	*Petrogale lateralis*	*Macroderma gigas*	*Chalinolobus morio*	*Falsistrellus mackenziei*	*Nyctophilus geoffroyi*	*Nyctophilus gouldi*	*Hydromys chrysogaster*	*Mus musculus*	*Notomys* sp. cf. *N. mitchellii*	*Pseudomys albocinereus*	*Pseudomys fieldi*	*Pseudomys nanus*	*Pseudomys occidentalis*	*Pseudomys shortridgei*	*Rattus fuscipes*	*Rattus tunneyi*	Total NISP	No. of taxa
3 mm sieve		A	0	15	0	2	0	0	0	205	9	0	0	1	4	0	0	0	0	0	3	4	0	0	0	5	0	0	0	0	0	45	154	2	0	199	41	28	11	**728**	**16**
	Banded orange and brown sediments	B	0	37	0	5	0	0	0	244	11	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	1	1	41	108	9	0	215	53	36	12	**776**	**15**
		C	0	44	0	9	0	0	0	215	6	0	0	0	2	0	4	0	0	0	0	1	0	0	5	0	0	0	0	0	0	54	59	12	0	215	56	29	26	**737**	**15**
	Brown sediment (1)	D	0	16	1	6	0	0	0	132	27	0	0	0	1	0	3	0	0	0	2	0	0	1	4	3	0	0	1	0	0	31	260	8	0	73	39	36	28	**672**	**19**
	Dark brown	E	1	25	1	3	0	0	0	108	3	0	2	0	1	0	1	0	0	0	1	1	0	0	2	3	0	0	0	0	0	25	248	14	0	32	40	10	16	**537**	**20**
	Brown sediment (2)	F	0	22	3	5	0	0	0	141	12	0	1	0	3	0	1	2	0	0	0	1	0	1	15	1	0	1	1	0	0	26	242	2	0	49	82	31	39	**681**	**22**
	Medium grained orange sediment	G	2	61	3	3	0	1	0	137	30	0	0	1	4	2	8	0	0	3	5	4	2	3	13	0	0	0	0	0	0	53	206	2	0	141	206	55	102	**1047**	**24**
	Light brown band	H	0	3	2	0	0	1	0	2	6	0	0	0	0	0	2	0	0	0	0	2	0	0	3	0	0	0	0	0	0	3	8	0	0	18	7	3	1	**61**	**14**
	Lime flecked sediment	I	0	9	0	0	0	0	0	33	4	0	0	1	0	0	1	0	0	0	3	3	0	0	0	1	1	1	0	0	0	7	33	1	0	34	27	11	10	**180**	**17**
	Mixed colour sediment	J	0	23	2	1	0	0	3	15	9	0	0	4	11	13	10	1	1	0	1	4	0	2	12	0	0	0	0	0	0	12	23	2	0	63	2	12	1	**227**	**23**
	Brown sediment (3)	K	0	4	3	2	0	0	0	5	4	0	0	0	1	3	4	0	0	1	0	0	0	0	1	0	0	0	0	0	0	6	13	0	0	22	3	6	1	**79**	**16**
	Lime flecked sediment	L	0	17	2	3	0	0	0	12	4	3	7	1	0	2	2	1	0	0	0	0	0	0	0	24	0	7	1	0	0	70	500	1	0	90	14	8	4	**773**	**21**
1 mm sieve	Brown sediment (3)	M	0	15	1	2	2	1	0	14	11	2	5	1	0	4	1	0	0	0	0	0	0	2	2	23	0	4	1	0	0	74	406	0	0	83	9	16	1	**680**	**23**
		N	0	10	0	1	2	0	0	11	4	0	2	0	3	1	3	0	0	1	0	0	0	2	1	22	0	1	0	0	0	65	464	2	1	101	11	8	1	**717**	**22**
		O	0	7	4	0	1	1	0	8	10	9	5	2	2	5	4	1	0	1	0	0	0	3	0	16	4	2	4	0	0	104	403	6	1	131	24	8	1	**767**	**27**
		P	0	10	7	0	4	0	0	27	17	6	3	2	6	11	3	3	0	1	1	2	1	1	5	12	0	6	1	0	0	85	340	4	0	126	25	20	1	**730**	**28**
		Q	0	9	4	2	0	0	0	23	13	8	0	4	8	16	5	0	1	4	2	1	0	3	0	8	1	0	3	0	0	86	305	7	0	99	14	18	0	**644**	**24**
		R	0	15	5	1	0	0	0	14	7	0	0	1	5	4	3	0	0	0	0	0	0	2	1	6	2	1	3	0	0	50	204	5	0	55	15	13	1	**413**	**22**

RESULTS

SEDIMENTOLOGY AND STRATIGRAPHY

The sedimentary sequence in Caladenia Cave is well stratified. No evidence of reworking of the sediments was observed, except where small burrows occurred (Figure 4). Unfortunately, many of the sediment samples collected by Roe were still damp when placed in vials, causing their paper labels to degrade to the point of illegibility, preventing sedimentological analyses.

CHRONOLOGY

Radiocarbon dates from the sedimentary sequence indicate that the majority of the deposit was undisturbed. Dates CC223 and CC231 are, however, out of sequence (Table 2; Figure 5), probably because of disturbance of sediment by rain washing into the open excavation after a storm (Roe 1974), which would have redeposited much younger material into the trench. All other dates are older and in stratigraphic order, with a high R^2 coefficient once the disturbed dates are excluded (Figure 5).

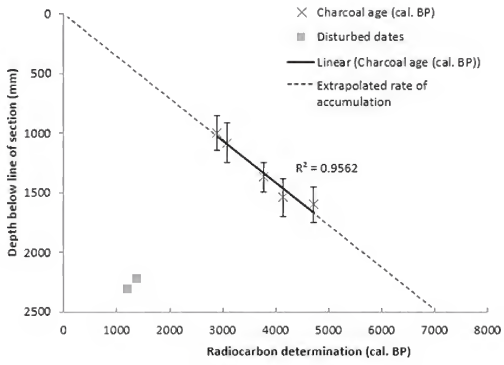

FIGURE 5 Depth-age plot for the deposit in Caladenia Cave. R^2 value does not include the two disturbed dates represented by grey squares.

TAPHONOMY

A majority of the small mammal (<250 g mean adult body weight) material recovered from the excavation was intact with very little, to no digestive erosion (Figure 6) or breakage on crania or long bones (Figure 7). This condition is typical of owl accumulation (Andrews 1990).

Mammalian predators and scavengers, *Sarcophilus harrisii, Thylacinus cynocephalus* and *Homo sapiens,* contributed to the Caladenia Cave assemblage. Evidence of *S. harrisii* includes coprolites and shards of bones of larger, indeterminate marsupials, still with a faecal coating, in Group J. Turtle shell and burnt bones, possible evidence of humans, were found in Group K. All specimens of species >250 g are incomplete, with saw-tooth breakage patterns and higher levels of surface digestive erosion, and many remains of animals larger than 1 kg showed evidence of human use (Monks et al. 2014) (Figure 6). The Shapiro-Wilk tests returned significantly low probabilities that both size classes were not normally distributed (see Appendix 3, Tables A3.1 and A3.3). Paired *t*-tests were then conducted, which highlighted that the two size classes are significantly different from one another taphonomically by both percent completeness and evidence of digestive erosion ($p<0.05$, see Appendix 3, Tables A3.2 and A3.4).

Species <250 g are generally represented by >90% complete specimens. While much more variable, remains of species >250 g often consisted of bone shards, or broken ends of long bones. Bone completeness of species <250 g generally decreased with depth in the deposit (Figure 7). This was attributed to the weight of the cave fill, trampling and a weakening of the bone

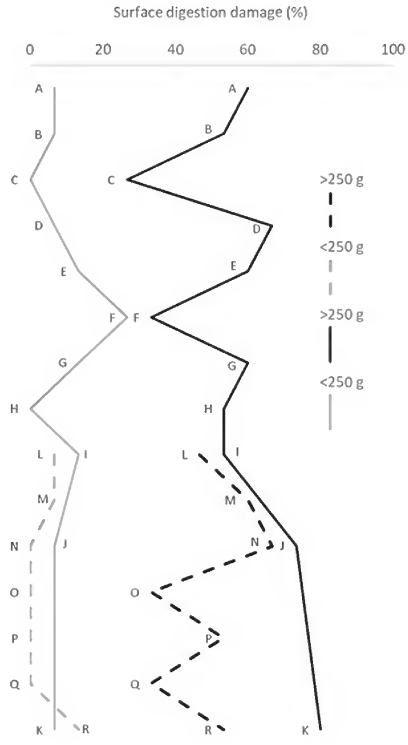

FIGURE 6 The proportion of damage caused by digestion to remains of species <250 g and >250 g. Damage was recorded as percentage of the bone surface showing digestive erosion or bite damage. Solid lines represent the Groups sieved with a 3 mm mesh aperture, dashed lines with a 1 mm aperture.

with age. The specimens recovered from species >250 g appear to have been damaged more by mammalian accumulators such as *S. harrisii*, *T. cynocephalus* and humans before their deposition.

Six burrows were observed in photographs and sketches of the excavation sections. Notable dark staining of all other specimens from the same depth as a single unstained, pale *Mus musculus* specimen is consistent with it having been recovered from a small burrow in the deposit (see Table 3). The mouse may have entered the burrow as a living animal, or its remains could have been reworked from the surface by whatever made the burrow. Either could explain its depth in the deposit in relation to its recent (<200 years) invasion of south-western Australia.

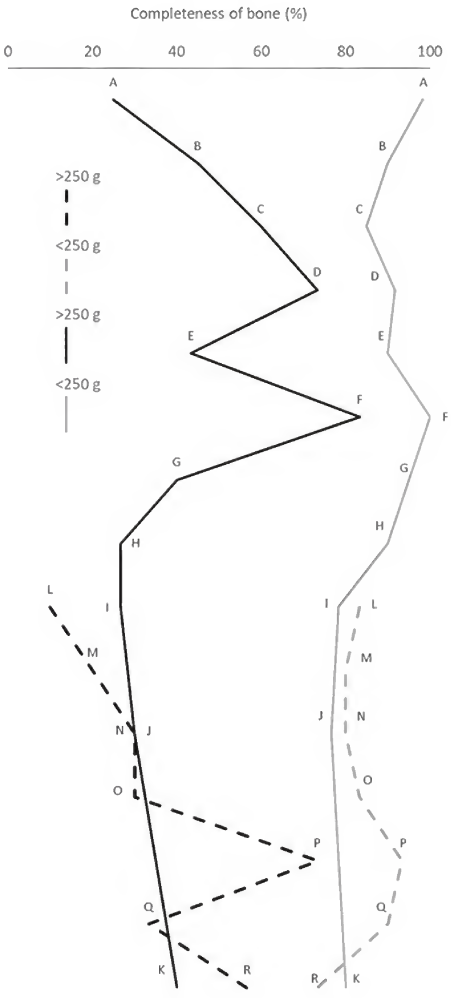

FIGURE 7 Bone breakage shown by remains of species <250 g and >250 g. Solid lines represent the Groups sieved with a 3 mm mesh aperture, dashed lines with a 1 mm aperture.

Cranio-dental preservation changed through the deposit, from specimens such as intact skulls and splanchnocrania in the upper 1000 mm to mainly small fragments of maxillae and dentaries recovered by the 1 mm sieve in Groups L–M and below. In material from the small sieve mesh aperture (L–R), the ratio of isolated rodent M1s to teeth-bearing bones changed, with most of the NISP counts constituted by molars alone. The mid-range Groups H–K (Figure 8) of the deposit contain higher relative abundances of remains of larger species (>250 g), resulting from natural deaths, scavengers or human accumulation.

The reduction in sieve size by the excavation team, evident in the sharp change in the relative abundance of <50 g species between Groups K and L (Figure 8), caused the differential recovery of smaller species.

FAUNA

A total of 12,407 specimens was identified from the Roe excavation in Caladenia Cave. These have been accessioned into the vertebrate palaeontological collection of the Western Australian Museum under catalogue numbers 13.11.1–13.11.999 and 13.12.1–13.12.617. In most cases only a single catalogue number was allocated to each species from each spit, irrespective of the number of specimens. Only 10,449 specimens were used for statistical analyses due to disturbance of some of the stratigraphy and excavation problems. The biggest change from species presence to absence occurs at approximately 1600 mm (Group J), where the marsupials *Phascogale calura*, *Perameles bougainville* and *Lagorchestes hirsutus* and the placental *Falsistrellus mackenziei* disappear. All of these species were recorded on the basis of jaws or jaw fragments large enough to be retained on a 3 mm sieve, and had their remains been present in the upper part of the deposit, where bone preservation was relatively good, they would have been recovered. The *Falsistrellus mackenziei* specimens have extended the known Holocene northern range limit of the species, which was previously Jandakot at 32°15'S, 115°50'E (Hosken and O'Shea 1995).

No easily distinguished species of *Sminthopsis* such as *Sminthopsis crassicaudata* was identified within the assemblage; other *Sminthopsis* species could not be separated from one another using the descriptions in Archer (1981) or Kitchener et al. (1984).

Sarcophilus harrisii was represented by jaw fragments, isolated teeth and ascribed coprolites. The coprolite specimens, containing small bone fragments, indicate that *Sarcophilus* contributed to the accumulation of vertebrate remains in the cave.

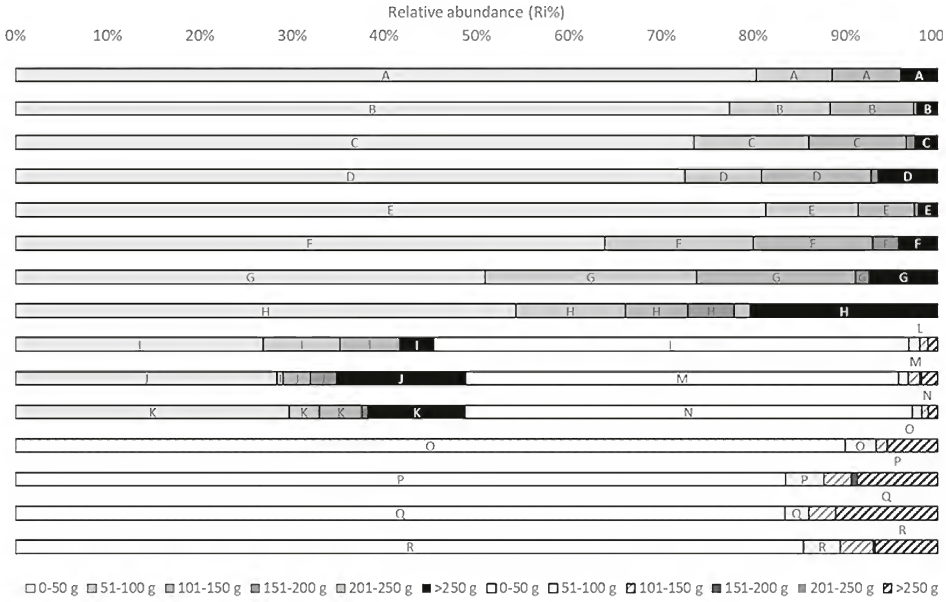

FIGURE 8 The relative abundance of the diagnostic remains recovered from each data Group in Caladenia Cave within allocated average body mass classes.

Evidence of human use of the cave includes hearths described and sketched in Roe's notebooks after a trench wall collapsed (Roe 1974, pp. 39–42). Freshwater mussel shells, turtle shell and fish bones were recovered as well as burnt mammal bone in the lower levels of the deposit (Monks et al. 2014). A fragment of human jaw bone was mentioned in Roe's notebooks (Roe 1971), but cannot be found in the Western Australian Museum collections. Artefacts were also found during the excavation, and catalogued into the Museum archaeological collection (B3086–90, B1979, B1981–82 and A22107–09) providing additional evidence that humans occasionally inhabited the cave.

Three specimens of *Thylacinus cynocephalus* were recovered from the excavation, each at different depths. The chronologically youngest specimen, a right metatarsal III of *Thylacinus cynocephalus* (WA Museum vertebrate palaeontological collection catalogue number 13.11.364) has an associated charcoal age of 3254–2925 cal. BP. All *Thylacinus* specimens were originally identified by Merrilees and confirmed by Thorn with Museum comparative material.

PALAEOECOLOGY

Rarefaction analysis of the NISP data from each Group (see Figures A–R in Appendix 4), indicated that the smallest Group samples, D, E and I, were all still within one standard deviation of the largest samples' rarefaction curves, and all samples tend towards an asymptote. Group I remained the only sample to not plateau. Therefore, sample sizes and species richness were sufficient for further statistical tests (Gotelli and Colwell 2001; Hammer and Harper 2008).

Correspondence analysis clearly shows a cluster of Groups screened with the 1 mm aperture sieve (circled in Figure 9). The smaller species, such as the microbats, *Pseudomys albocinereus*, and *Phascogale calura* are associated with the 1 mm sieve aperture Groups, while

TABLE 4 Relative abundances of species grouped according to body mass (g) in the 3 mm and 1 mm sieve mesh aperture samples. Body mass data could not be located for some species, therefore Ri% figures do not total 100.

Mass (g)	3 mm (Ri%)	1 mm (Ri%)
0–50	53.90047	86.89071
51–100	9.43340	2.80774
101–150	8.31425	2.22037
151–200	1.52893	0.19437
201–250	0.15771	0.03963
>250	8.75636	5.44026

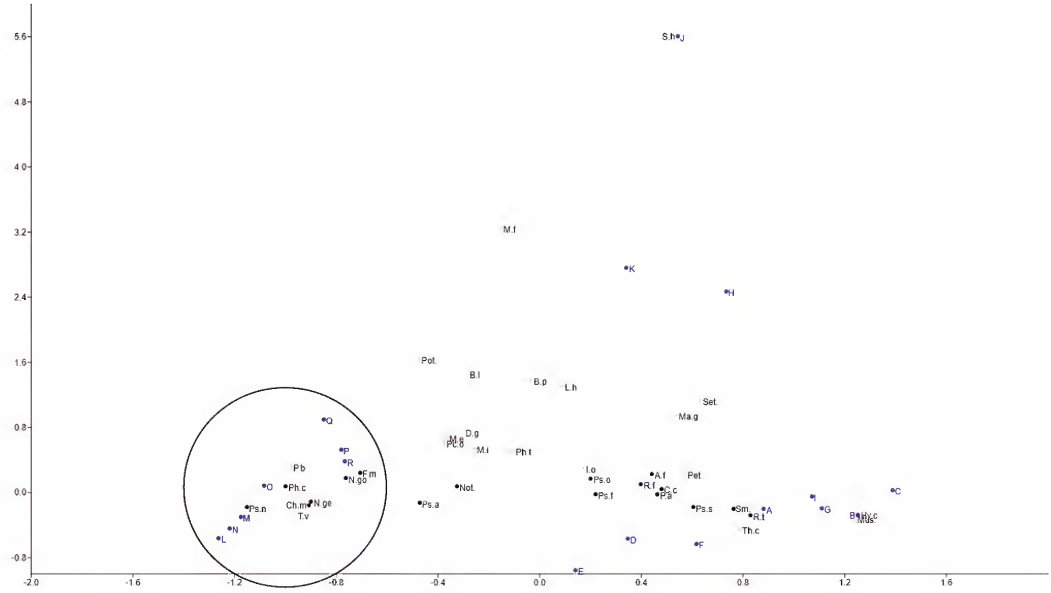

FIGURE 9 Scatter plot of the first two axes of correspondence analysis of the raw Group data from Caladenia Cave. Groups A–K are from the 3 mm sieve and Groups L–R from the 1 mm. Species >250 g are designated with a grey '+'. Clustered Groups correlating with the 1 mm sieve are circled, note that this is not a 95% confidence ellipse. A.f = *Antechinus flavipes*, D.g = *Dasyurus geoffroii*, Pa = *Parantechinus apicalis*, Ph.c = *Phascogale calura*, Ph.t = *Phascogale tapoatafa*, S.h = *Sarcophilus harrisii*, Sm. = *Sminthopsis* sp. indet, I.o = *Isoodon obesulus*, P.b = *Perameles bougainville*, T.v = *Trichosurus vulpecula*, B.l = *Bettongia lesueur*, B.p = *Bettongia penicillata*, Pot. = *Potorous platyops*, M.e = *Macropus eugenii*, M.f = *Macropus fuliginosus*, M.i = *Macropus irma*, Pet. = *Petrogale lateralis*, Set. = *Setonix brachyurus*, C.c = *Cercartetus concinnus*, Pc.o = *Pseudocheirus occidentalis*, Ma.g = *Macroderma gigas*, Ch.m = *Chalinolobus morio*, F.m = *Falsistrellus mackenziei*, N.ge = *Nyctophilus geoffroyi*, N.go = *Nyctophilus gouldi*, Hy.c = *Hydromys chrysogaster*, Mus. = *Mus musculus*, Not. = *Notomys* sp. cf. *N. mitchellii*, Ps.a = *Pseudomys albocinereus*, Ps.f = *Pseudomys fieldi*, Ps.n = *Pseudomys nanus*, Ps.o = *Pseudomys occidentalis*, Ps.s = *Pseudomys shortridgei*, R.f = *Rattus fuscipes*, R.t = *Rattus tunneyi*.

most of the larger species do not obviously cluster with any Group. Notably, *Sarcophilus* sits directly under Group J, and *Hydromys* and *Mus musculus* under Group B, as these species appear only in these Groups. The remaining rodents and dasyurids are generally spread out across the plot, not clustering with any particular Group, possibly due to variation in preservation causing them to be variably retained by both sieves throughout the deposit.

When the different faunal size classes were further examined (Table 4) the relative abundances of the smallest species (<50 g) were significantly higher in Groups where a 1 mm sieve was used ($p < 0.05$).

The Simpson index of diversity was found to be fairly consistent through the upper levels of the deposit until the change in sieve size between Groups K and L (Figure 10). The Groups I–K record a Simpson index of 0.8 or higher, while the same depths sieved with the 1 mm aperture, represented by Groups L–N, drop to 0.5. Despite an increase in sample size the diversity index does not revert again until Group R. This may be explained by an increase in the recovery of smaller specimens resulting from a finer sieve mesh aperture. Relative abundance of 0–50 g species increased from 53.9% to 86.9% of the recovered material (Table 4), but while the sample sizes increased, the number of taxa did not, generating a false impression of a drop in diversity.

Species were grouped into habitat guilds based on current knowledge of ecological preferences, after Adams et al. (2016). Relative abundances of habitat guilds show major fluctuations below Group G (Figure 11). This is most likely to have been caused by differential recovery of the material in those spits that were only sampled by the 3 mm sieve, whereas the same depths covered in Groups L–R, sampled with the 1 mm sieve, from the other 'End' of the trench, show much less fluctuation.

DISCUSSION

The investigation into the fossil vertebrate fauna of Caladenia Cave unearthed a total of 38 native mammal species, consisting of 14 placentals and at least 22 marsupials (*Sminthopsis* and *Dasycercus* were only identified to genus and could each represent two or more species). Current faunal records report only 11 extant native species, the top layer of the deposit alone records 16, and historical records place 28 species in the same area (Wilson et al. 2012). These figures highlight the value of Holocene fossil deposits as records of the original mammalian species richness of the Swan Coastal Plain. The drop in species richness on the northern Swan Coastal Plain can only be attributed to the impacts of European settlement, as other factors, the changes in rainfall or the arrival of the dingo in the area, have not produced the same dramatic effect anywhere in this long-term data set.

TAPHONOMY

The body mass range, condition and breakage patterns observed in a majority of the fossil mammal assemblage from Caladenia Cave are characteristic of an owl accumulation (Andrews 1990; Lyman 2012a). *Tyto delicatula* Gould, 1837, the Australian barn owl, is the species most likely responsible for the accumulation, as a majority of the postcranial material examined shows little or no digestive erosion of the bone surface and most long bones are intact (see Figures 6–7). *Tyto delicatula* has been recorded on the northern Swan Coastal Plain (Storr et al. 1978; Atlas of Living Australia 2013). The majority of the prey material is composed of rodents and small marsupials, most of which can be swallowed whole by owls (Morton and Martin 1979; Andrews 1990; McDowell and Medlin 2009).

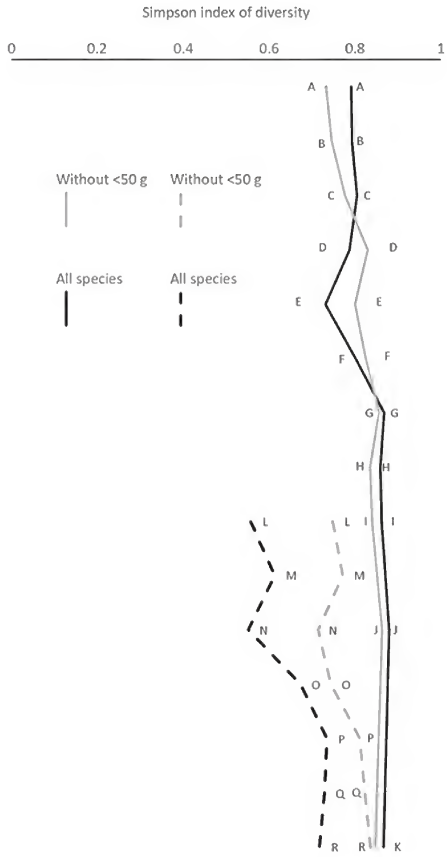

FIGURE 10 Simpson index of diversity of each Group in Caladenia Cave. When all species with a body mass of less than 50 g were removed from the entire dataset, diversity across the deposit appears more even. Solid lines represent the Groups sieved with a 3 mm mesh aperture, dashed lines with a 1 mm aperture.

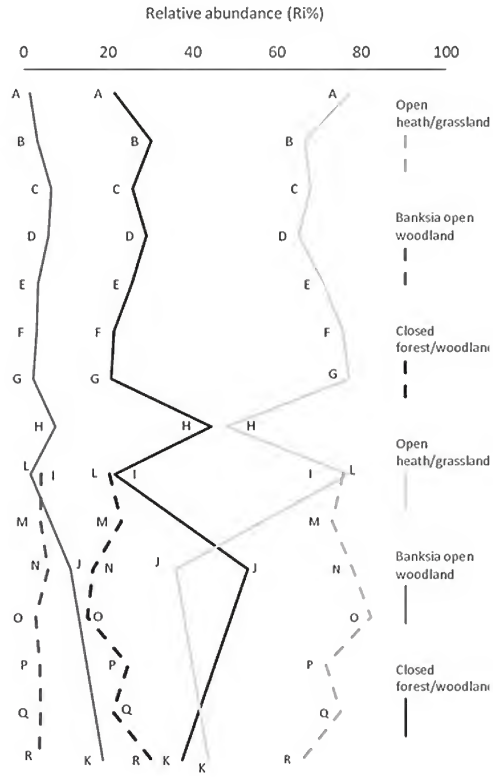

FIGURE 11 Changes in relative abundances of habitat guilds of fossil mammal species >50 g in Caladenia Cave. Species were grouped according to information displayed in Appendix 1.

The use of a sieve of larger mesh aperture for the upper levels of the excavation caused differential recovery of the largest and loss of the smallest mammals, particularly in the deeper layers where the bone was more fragile, creating a bias in the species' relative abundances through time (Lyman 2012b). Where the 3 mm sieve was used, a lower proportion of the smaller species such as *Sminthopsis* sp. indet., *Cercartetus concinnus, Chalinolobus morio* and *Pseudomys albocinereus* was recovered, as evident in the correspondence analysis (Figure 9). Isolated molars, canines or even entire maxillae from these species with a minimum dimension of ~2 mm, were less likely to be retained than those of larger species (Lyman 2012b). Although Caladenia Cave was excavated in the 1970s, differential recovery is still not uncommon in palaeontological and archaeological investigations and is often not considered in analyses (Baynes personal observation 2016). The results of the Caladenia Cave analyses demonstrate that sieve bias can overwhelm the palaeoecological signal in relative abundance data. Screen mesh aperture is an important factor that should be considered in planning the methodology of an excavation. Preliminary research into the size of the expected specimens, and how they were accumulated is wanted, as well as the use of an appropriate minimum sieve mesh aperture when small faunal material is present in a deposit.

EVIDENCE FOR CLIMATE CHANGE

Three semi-arid and arid-dwelling species, *Phascogale calura* (Figure 12), *Perameles bougainville* and *Lagorchestes hirsutus*, are present in the deposit below a depth of 1540–1600 mm (Group J, 4868–4569 cal. BP; Table 2), but absent above it. These three species are part of a suite of six which shows the same pattern of change from presence to absence in the mid Holocene levels of the deposit in Hastings Cave, about 120 km north of Caladenia Cave on the Swan Coastal Plain (Baynes 1979). Moreover, there are no specimens of the three species in the Western Australian Museum vertebrate palaeontological collection from cave floor surface faunas (of late Holocene age) from any of the many caves in the northern Swan Coastal Plain represented in that collection; see, for example, the distribution records for *P. calura* in Figure 12. This pattern of faunal change suggests that local winter rainfall increased. The other semi-arid and arid proxy species in this group (*Perameles bougainville* and *Lagorchestes hirsutus*) also have live-caught records from areas of low winter rainfall (Atlas of Living Australia 2013).

Support for this change was previously found south of Caladenia Cave: invertebrate climate proxies relating to the flow of the Swan River indicating an increase in effective rainfall since 4853–4292 cal. BP (Kendrick 1977; Yassini and Kendrick 1988).

PALAEOECOLOGY

The change in sieve mesh aperture size generated a more precise representation of the <50 g mammals in the lower layers of the Caladenia Cave deposit. This action, taken part way through the excavation, means that the bulk of the youngest material collected has been biased such that smaller mammals are underrepresented. Correspondence analysis was initially applied to the relative abundances of each species recovered from each layer. The resulting plot shows that species and layers grouped in accordance with the size of the sieve used (Figure 9). Consequently, an unbiased interpretation of ecological change over time based on relative abundances was not possible (see also Figure 10 for how diversity, calculated with relative abundances, was impacted by differential recovery). The change in sieve size appears to correlate directly with the change in abundance of the smallest species (<50 g), which in turn affects the Simpson diversity index for Groups L–R where sample size increases but species richness does not, creating a downward trend in overall diversity in comparison to Groups I–K (3 mm sieved units). Change

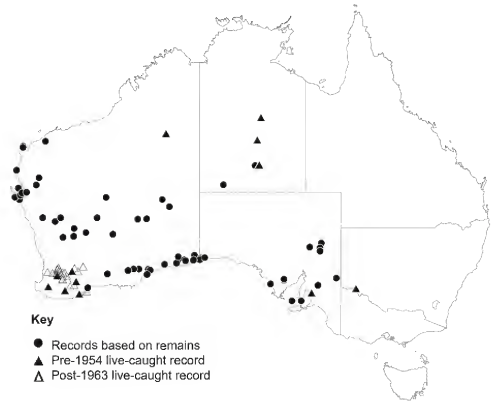

FIGURE 12 The distribution of *Phascogale calura*. The species was restricted to areas characterised by persistently dry hot summers, with semi-arid to arid climates (Kitchener et al. 1980; Australian Bureau of Meteorology 2013). The gap between mid-latitude and southern records in Western Australia reflects a lack of sites containing mammal remains rather than an absence of original populations, except that, being arboreal, *P. calura* did not occur on the treeless Nullarbor Plain. Data from Thomas (1888), Wakefield (1966), Parker (1973), Baynes and Baird (1992), Baynes and Johnson (1996), Baynes and McDowell (2010), the vertebrate palaeontological and mammal collections of the Western Australian Museum and the mammal collection of the South Australian Museum.

in the preservation of material seems to also have disrupted any ecological patterns in the data, evident in the 'noise' shown in Figure 11. A trend of mostly open heath/grassland species appears to be disrupted in units L–G by an increase in larger species' relative abundance. This is most likely due to the taphonomic features of bone breakage and digestion (Figures 6 and 7) decreasing preservation of the bone, leading to differential recovery in the 3 mm sieved Groups.

An important finding uncovered by the excavation of Caladenia Cave, not impacted by differential recovery, is the presence of a specimen of *Thylacinus cynocephalus* with an associated radiocarbon date of 3254–2925 cal. BP. Until now, the youngest mainland Australian specimen of *Thylacinus* is dated to 3379–3060 cal. BP (McDowell 1997). The timing of the mainland thylacine extinction has been directly associated with the arrival of the dingo at 3904–3445 cal. BP (Milham and Thompson 1976). Fillios et al. (2012) described the impact of dingo immigration on the fauna of mainland Australia as a 'trophic cascade', as it interrupted the thylacine's suppressive effect on herbivores and small predators, indirectly impacting smaller herbivores and vegetation. By contrast, the only significant faunal change discovered in Caladenia Cave pre-dates the arrival of the dingo. Similar results were found in an investigation of Hastings Cave (Baynes 1979), demonstrating a lack of evidence for any 'trophic cascade' occurring on the northern Swan Coastal Plain.

Other than the loss of the dry-land species due to increased rainfall, fine scale local changes in the palaeoecology of the northern Swan Coastal Plain cannot be elucidated. The continued presence of most species throughout the assemblage suggests ecological stability during the Holocene, despite apparent changes in rainfall or the arrival of the dingo. This is in contrast to the effects of European settlement in the area which resulted in local extinction of many mammals such as *Parantechinus*, *Pseudocheirus* and five of the seven native rodent species, and a drastic change from all native vegetation to an agricultural mosaic

THE FUTURE

Because of the limitations imposed on the Caladenia Cave data by differential recovery of mammal remains, further research is needed to elucidate the relationships between the original biotic communities of the Swan Coastal Plain. A re-investigation of the vertebrate assemblage in Wedge's Cave (Lundelius 1960), the ongoing investigation of Yellabiddie Cave (Monks et al. 2016) or another excavation of the East Moore caves, may provide the material required for a palaeoecological comparison with both Hastings and Caladenia Cave. This study shows that excavated sediment must be processed using a 1 mm or 0.5 mm sieve mesh aperture for the entire excavation. Unfortunately, future excavation of Caladenia Cave would not be practical as the ideal location and much of the remaining sediment has already been disturbed. However, 30 other caves have been recorded in the 'Lower South West' region that should be explored for fossil remains (Matthews 1985). Evidence collected from other caves further south could also extend the range of interpretation of the Holocene Swan Coastal Plain and provide more information for restoration ecology.

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APPENDIX 1 Species guild designation references

TABLE A1 Grouping of non-volant mammal species into vegetation guilds according to the references below. These groupings were used for Figure 11.

	Species	Baynes 1979	Dortch 2004	Van Dyck & Strahan 2008	Adams et al. 2016
Closed Forest/Woodland	*Antechinus flavipes*	x		x	x
	Dasyurus geoffroii	x		x	
	Phascogale tapoatafa	x		x	x
	Sarcophilus harrisii	x		x	x
	Isoodon obesulus	x		x	x
	Trichosurus vulpecula	x		x	x
	Potorous platyops			x	x
	Setonix brachyurus	x	x	x	
	Pseudocheirus occidentalis	x		x	
Banksia Open Woodland	*Parantechinus apicalis*	x		x	
	Phascogale calura	x		x	
	Bettongia penicillata	x		x	x
	Cercartetus concinnus	x		x	x
	Pseudomys occidentalis	x		x	x
Heath/Grassland	*Perameles bougainville*	x	x	x	x
	Bettongia lesueur	x	x	x	x
	Lagorchestes hirsutus	x		x	
	Macropus eugenii	x	x	x	x
	Macropus fuliginosus	x		x	x
	Macropus irma	x		x	
	Petrogale lateralis	x	x	x	
	Notomys mitchellii			x	
	Pseudomys albocinereus	x		x	
	Pseudomys fieldi	x		x	
	Pseudomys shortridgei	x		x	x
	Rattus tunneyi	x		x	

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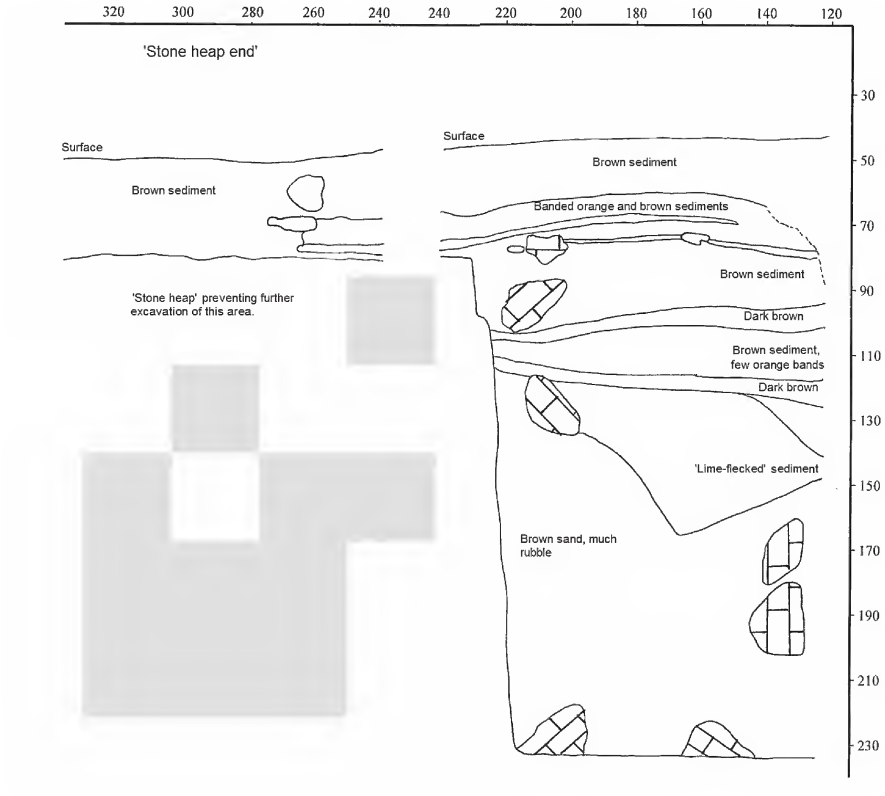
APPENDIX 2 Section of 'Stone heap end' and test pit

FIGURE A2 Section illustration of 'Stone heap end' and the centralised test pit, originally drawn by Duncan Merrilees, traced, digitised and labelled by Thorn. See Table 1 in the paper for details on how the stratigraphy was assigned into spits and units. The test pit shown below was added at the suggestion of Merrilees after review of Roe's notes on the excavation (Roe 1971).



APPENDIX 3 Statistical tests for the taphonomic two size classes

TABLE A3.1 Shapiro-Wilk test for normality in the distribution of the digestion damage data within the two sizes.

	<50 g	>250 g
N	54	54
Shapiro-Wilk W	0.5919	0.9271
p(normal)	5.25E-11	0.002808

TABLE A3.2 Paired *t*-test to see if the <50 g class and the >250 g class show similar rates of digestion damage.

	<50 g		>250 g
N	51		
Mean	0.37255		2.6863
Median	0		3
t-test	-10.99	p(same)	6.06E-15

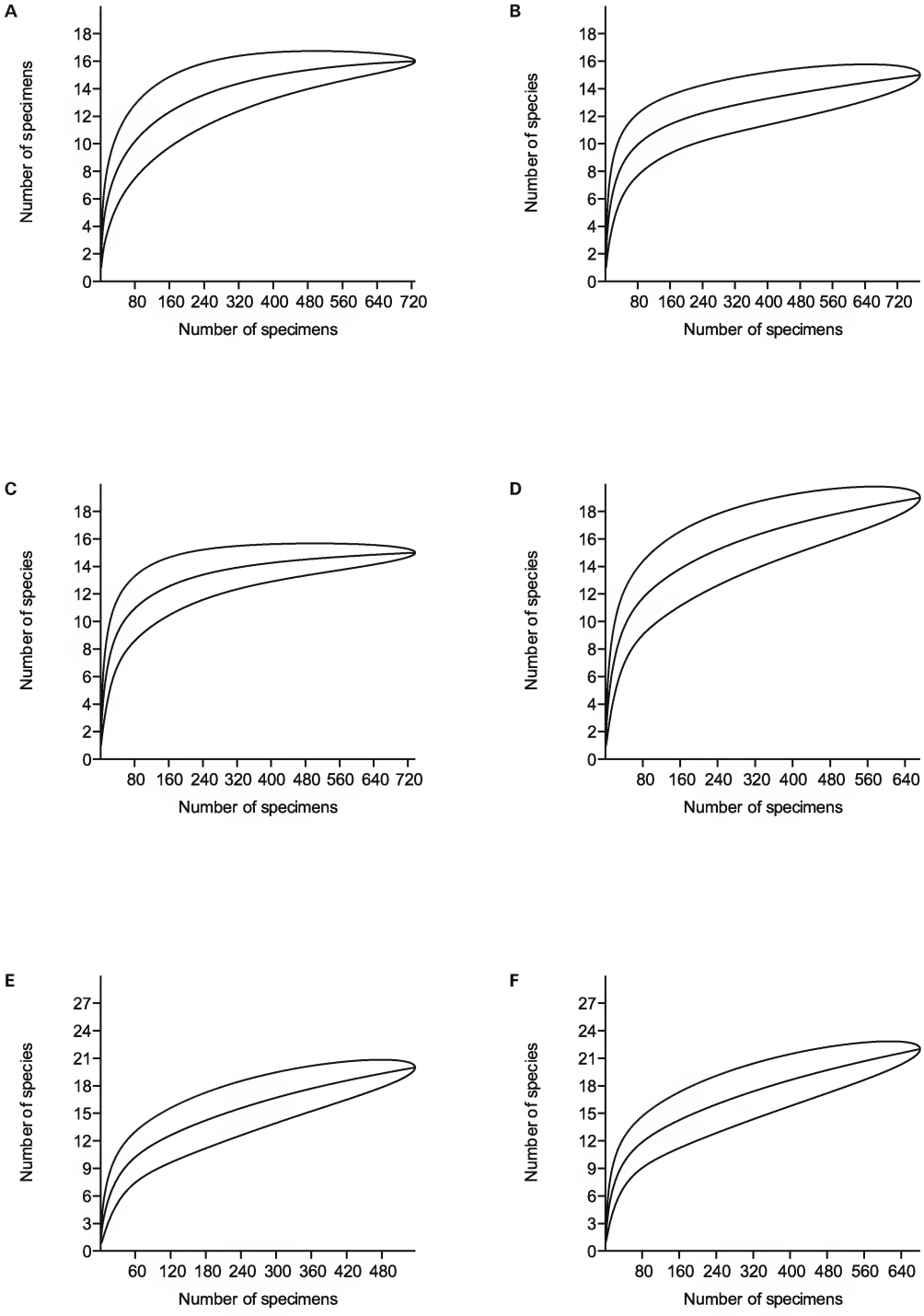
TABLE A3.3 Shapiro-Wilk test for normality of the bone breakage data within the two size classes, <50 g and >250 g.

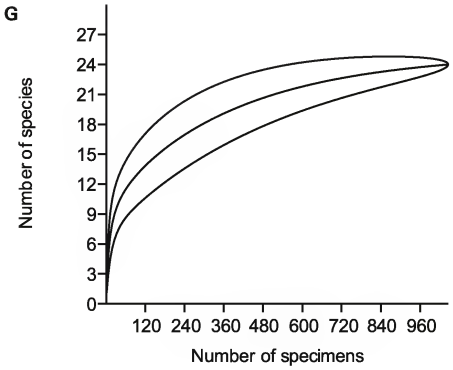
	<50 g	>250 g
N	54	54
Shapiro-Wilk W	0.864	0.8547
p(normal)	2.02E-05	1.08E-05

TABLE A3.4 Paired *t*-test to see if the <50 g class and the >250 g class show similar rates of bone breakage.

	<50 g		>250 g
N	51		
Mean	86.373		45.98
Median	90		30
t-test	7.848	p(same)	2.86E-10

APPENDIX 4 FIGURES A4A–R Rarefaction graphs to test for sufficient sample size in each of the Groups (A–R) listed in Table 1.

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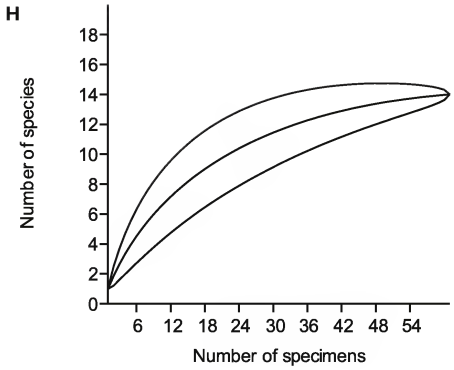
Number of species
0 3 6 9 12 15 18 21 24 27
120 240 360 480 600 720 840 960
Number of specimens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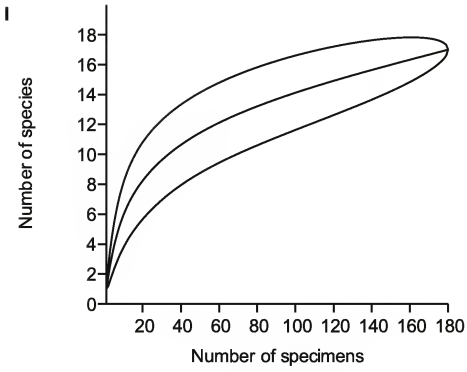
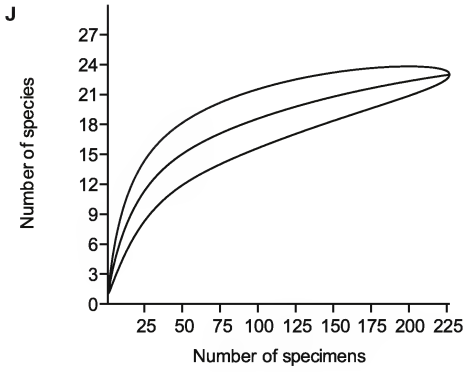
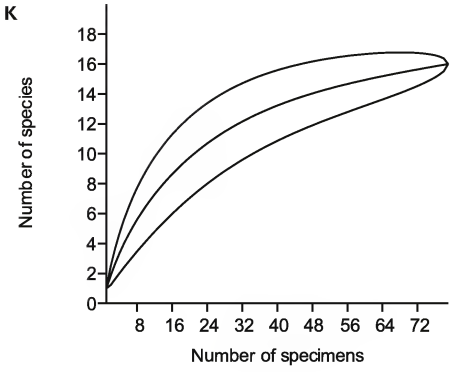
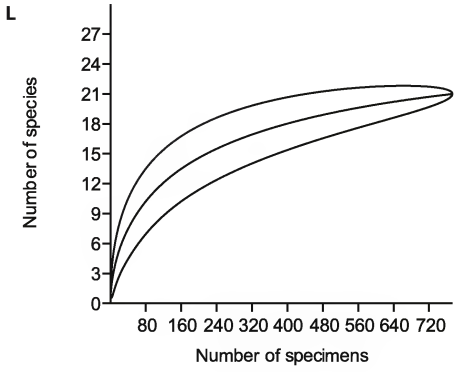
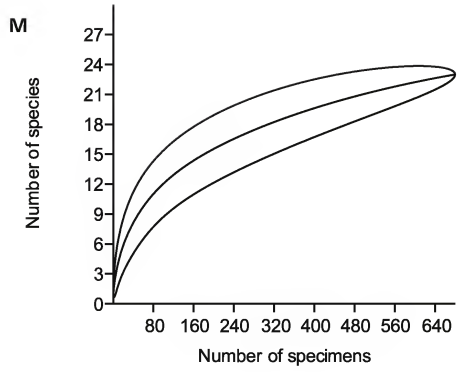
Number of species
0 2 4 6 8 10 12 14 16 18
6 12 18 24 30 36 42 48 54
Number of specimens


I
Number of species
0 2 4 6 8 10 12 14 16 18
20 40 60 80 100 120 140 160 180
Number of specimens


J
Number of species
0 3 6 9 12 15 18 21 24 27
25 50 75 100 125 150 175 200 225
Number of specimens


K
Number of species
0 2 4 6 8 10 12 14 16 18
8 16 24 32 40 48 56 64 72
Number of specimens


L
Number of species
0 3 6 9 12 15 18 21 24 27
80 160 240 320 400 480 560 640 720
Number of specimens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Number of species
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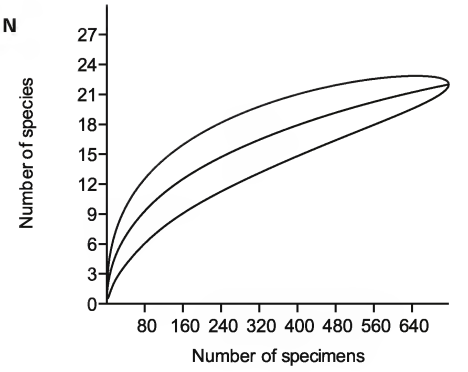
80 160 240 320 400 480 560 640
Number of specimens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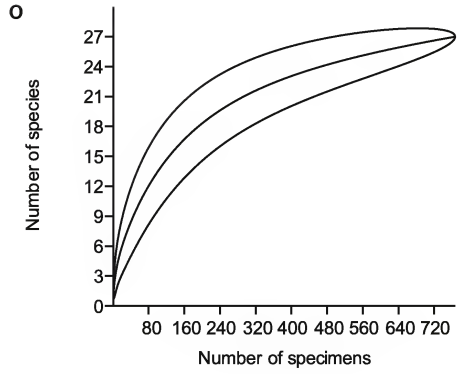
Number of specimens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Number of species
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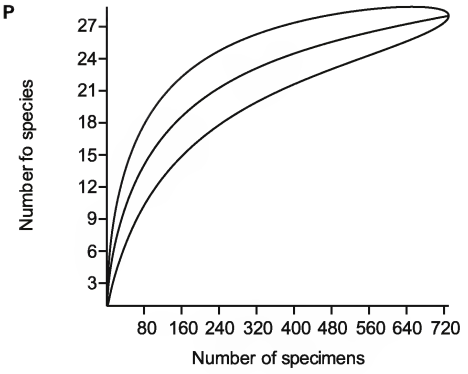
Number of specimens


P
Number fo species
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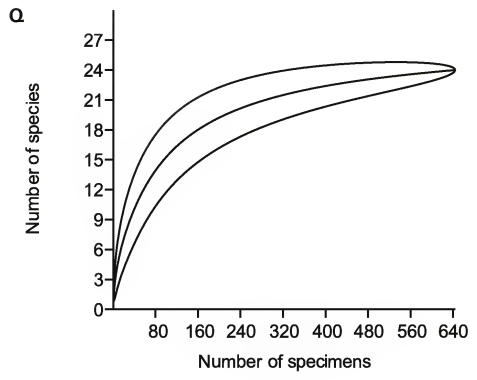
Number of specimens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Number of species
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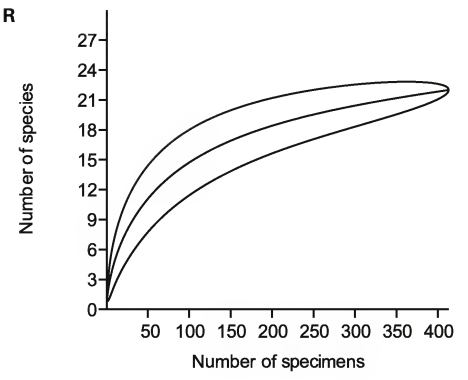
80 160 240 320 400 480 560 640
Number of specimens


R
Number of species
0 3 6 9 12 15 18 21 24 27
50 100 150 200 250 300 350 400
Number of specimens

 DOI: 10.18195/issn.0312-3162.32(2).2017.237

A replacement name for *Macranillus* Baehr, 2016 (Insecta: Coleoptera: Carabidae: Bembidiini: Anillina)

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ABSTRACT – The recently described genus *Macranillus* Baehr, 2016, has been shown to be a junior homonym of *Macranillus* Sharp, 1903, a genus of Bembidiini, which, however, is a synonym of *Bembidion*, subgenus *Nesocidium* Sharp, 1903. This renders the genus-group name *Macranillus* Baehr, 2016 as unavailable, and the genus is herein renamed as *Magnanillus* gen. nov. The five subterranean species originally included in *Macranillus* are transferred to *Magnanillus*.

KEYWORDS: taxonomy, new genus, Western Australia

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INTRODUCTION

The genus-group name *Macranillus* Baehr, 2016 was described in a recent publication dealing with subterranean beetles from the Pilbara region of Western Australia (Baehr and Main 2016). *Macranillus* includes five species of Bembidiini from deep bores in layered sandstone. Unfortunately, the name is preoccupied by *Macranillus* Sharp, 1903, which was originally described for the carabid *M. coecus* Sharp, 1903, from the Hawaiian islands (Sharp, 1903). Although this name, according to Lorenz (2005), is a junior synonym of *Bembidion* and of the subgenus *Nesocidium* Sharp, 1903, it has priority over *Macranillus* Baehr, 2016 and thus is not available (International Commission on Zoological Nomenclature 1999).

To avoid further confusion, the genus *Macranillus* Baehr, 2016, is hereby renamed *Magnanillus*, gen. nov. It contains five species, all originally described in the genus *Macranillus* Baehr, 2016.

Magnanillus nom. nov.

urn:lsid:zoobank.org:act:835DF98B-C455-4874-BDBB-D356C7114CF7

TYPE SPECIES

Macranillus bennetti Baehr, 2016.

INCLUDED SPECIES

Magnanillus bennetti (Baehr, 2016), comb. nov.
Magnanillus magnus (Baehr, 2016), comb. nov.
Magnanillus maini (Baehr, 2016), comb. nov.
Magnanillus pearsoni (Baehr, 2016), comb. nov.
Magnanillus quartermainei (Baehr, 2016), comb. nov.

REMARKS

All species of *Magnanillus* are very large, depressed, rather parallel-sided species, which have been sampled from deep bores up to the depth of almost 80 m in old, layered sandstone rock in the Pilbara region in north-eastern Western Australia (Baehr and Main 2016).

ACKNOWLEDGEMENTS

I thank Mark Harvey of Western Australian Museum, Perth, who directed my attention to the genus described by Sharp many years ago.

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